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VOL. XVI, NO. 1 JANUARY, 1923

THE SCIENTIFIC MONTHLY

EDITED BY J. McKEEN CATTELL

CONTENTS

SOCIAL LIFE AMONG THE INSECTS. Professor William Morton Wheeler----- 5

THE THEORY OF RELATIVITY AND ITS INFLUENCE ON SCIENTIFIC THOUGHT. Professor Arthur Stanley Eddington---------- 34

FAST AND FAMINE. Professor S. Morgulis---------- 54

ZOOLOGY AND THE COLLEGE CURRICULUM. Professor H. H. Nininger----- 66

TOIL AS A FACTOR IN HUMAN EVOLUTION. Professor Ralph E. Danforth---------- 73

CITY GROWTH AND CITY ADVERTISING. Robert M. Brown---------- 80

METHUSELAH OF THE MISSISSIPPI. Dr. R. E. Coker---------- 89

THE PROGRESS OF SCIENCE:

The Body Guard; To Exchange a Chemical for a Colony; The Wastefulness of Agriculture; What is the Matter with the Artists? Scientific Items-------104

THE SCIENCE PRESS

PUBLICATION OFFICE: 100 LIBERTY ST., UTICA, N. Y.

EDITORIAL AND BUSINESS OFFICE: GARRISON, N. Y.

New York Office: The Grand Central Terminal

Single Number, 50 Cents. Yearly Subscription, $5.00

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THE SCIENTIFIC MONTHLY

JANUARY, 1923

SOCIAL LIFE AMONG THE INSECTS[1]

By Professor WILLIAM MORTON WHEELER

BUSSEY INSTITUTION, HARVARD UNIVERSITY

LECTURE V. PARASITIC ANTS AND ANT GUESTS

THE ants are so favorable for the study of certain phenomena which I have been unable to more than touch on in the preceding lectures that I have set this lecture apart for their fuller consideration. I allude to the phenomena which biologists embrace under the terms "symbiosis" or "mutualism" and "parasitism." Social life may, indeed, be regarded merely as a special form of symbiosis. This term, which signifies the living together of organisms in a balanced, cooperative, reciprocally helpful manner, is commonly applied interspecifically, that is, to partners thus related but belonging to different species, but there is no reason why it should not be applied to the same kind of relations between individuals of the same species, that is intraspecifically. Symbiosis is probably never realized in its ideal form, which would require that each of the partner organisms should render to the other in food or services an exact equivalent of what it receives. So great is the greed of organisms that one member of the partnership usually tends to snatch more than its share of the profits accruing from the association. One member is therefore exploited, while the other becomes correspondingly dependent, that is, parasitic. In some groups of animals symbiotic, or mutualistic relations may thus lapse into parasitism, but it seems to me improbable that parasitism among insects has had such an origin. The common and perhaps exclusive source of the phenomenon among these highly specialized organisms is predatism. In fact, the most typical of parasitic insects are really refined predators, which usually, on growing to their full stature, kill the hosts they have been carefully sparing and, one might say, using as food-getting instruments.

[1] Lowell Lectures.

Since this is not exactly the form of parasitism exhibited by other organisms, such as the tape-worms, certain barnacles and bacteria, I prefer to call it "parasitoidism."

Yet even among the insects there are so many kinds and degrees of dependence on other insects that a concise classification is impossible. The phenomena are extremely diverse and protean, merging and melting into one another in the most bewildering manner. My limited time and the exigencies of exposition therefore compel me to condense and schematize. I am, moreover, dealing with a small fragment of a vast subject. The whole organic world is burdened with parasitism, so shackled and impeded by it that progressive evolution becomes inhibited in every group in which it appears, and the classes that have escaped its paralyzing touch are very few. Professor J. M. Clarke has shown that parasitism made its appearance in marine animals as early as the Cambrian and that it has kept recurring ever since, specializing and leading to "degeneration" and thus robbing group after group of species of all hope of further progress. Although they may persist for ages they are doomed to extinction, and only the independent forms, those that neither lapse into parasitic habits nor waste their vitality in nourishing parasites, stand any chance of becoming the ancestors of future types. We therefore belong to a lineage which, by some rare good fortune, escaped all the culs-de-sac of parasitism—till we became social.

The very conditions of social life tend to facilitate the development of the host and parasite relations. Not only do the members of a society become more tolerant of alien organisms in their midst and even domesticate and breed them, but the nests and domiciles because of the protection they afford, their higher temperature, the stores of food, the refuse even, the helpless young and infirm old they contain—all representing so much nourishment—attract hordes of predators, scavengers, inquilines, guests and parasites in the strict sense of the word. And the crowding together of the social organisms greatly facilitates the interchange of all kinds of small parasites, such as mites, moulds and bacteria from host to host. On the other hand, the members of a society are themselves normally temporary parasites of one another, the young of the adults, the old of the young, and even the whole colony, as a unit, may become a temporary or permanent parasite on the colony of some other species. We noticed cases of this kind among the social wasps and bees, namely, *Vespa arctica* and *austriaca* and the various species of Psithyrus, and we shall find more numerous examples among the ants. I did not have time even to enumerate the alien beetles, flies, etc., that live in the nests

of the social wasps and bees, but they are numerous, and we shall find that the termites are surpassed only by the ants in the number of their parasites.

Although man furnishes the most striking illustrations of the ease with which both the parasitic and host rôles may be assumed by a social animal, his capacities in these directions have been little appreciated by the sociologists. Massart and Vandervelde seem to be the only authors who have attempted to do justice to the matter. Our bodies, our domestic animals and food plants, dwellings, stored foods, clothing and refuse support such numbers of greedy organisms, and we parasitize on one another to such an extent that the biologist marvels how the race can survive. We not only tolerate but even foster in our midst whole parasitic trades, institutions, castes and nations, hordes of bureaucrats, grafting politicians, middlemen, profiteers and usurers, a vast and varied assortment of criminals, hoboes, defectives, prostitutes, white- slavers and other purveyors to antisocial proclivities, in a word so many non-productive, food-consuming and space-occupying parasites that their support absorbs nearly all the energy of the independent members of society. This condition is, of course, responsible for the small amount of free creative activity in many nations. Biology has only one great categorical imperative to offer us and that is: Be neither a parasite nor a host, and try to dissuade others from being parasites or hosts. Of course, this injunction is no more easily obeyed than Kant's famous imperative, of which it embodies the biological meaning, for a parasite always treats its host as a means and not as an end, and the thoroughly parasitized host must abandon all hope of being an end in itself.

I have expressed myself somewhat drastically on human parasitism. If I attempted to utter all my opinions on the subject I should probably not be permitted to survive till the next lecture, even in so tolerant a community as Boston. But so vividly are the development and consequences of biological dependence illustrated by the ants that by confining myself to them, and possibly allowing a hint to escape here and there, you will be able to construct your own analogies. The more striking relations of ants to other organisms are enumerated in the accompanying list. I considered the relations to the Phytophthora (Fig. 78) in the preceding lecture, and our knowledge of the relations to the higher plants is in a state too controversial to admit of satisfactory exposition within the limits of this lecture. We may therefore confine our attention to social parasitism, or the behavior of ants as parasites and hosts of one another and to the myrmecophiles, or animals that use the ants as hosts. Social parasitism is exhibited by two

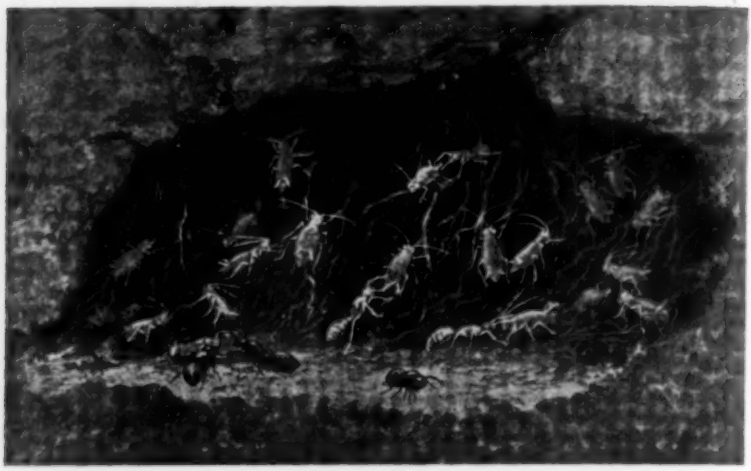

FIG. 78

Ants attending aphids on the roots of grasses and other herbs. (From a drawing by T. Carreras, after E. Step.)

series of species, one in which the parasitic and host colonies occupy separate though contiguous nests and therefore rear their broods in separate chambers, or nurseries, the other in which the two colonies have become so intimately united that they occupy a single nest and bring up their young in common. It will be seen that not only each of these series, but also that of the myrmecophiles begins in predatory (indicated by asterisks) and terminates in definitively parasitic relations.

RELATIONS OF ANTS TO OTHER ORGANISMS

I. SOCIAL PARASITISM (Ants as Parasites)
- A. *Compound Nests* (Broods reared separately)
  - *1. Brigandage (Cleptobiosis)
  - *2. Thievery (Lestobiosis)
  - 3. Neighborliness (Plesiobiosis)
  - 4. Tutelage (Parabiosis, Phylacobiosis)
  - 5. Hospitality (Xenobiosis)
- B. *Mixed Colonies* (Broods reared together)
  - *1. "Slavery" (Dulosis)
  - 2. Temporary Social Parasitism
  - 3. Permanent Social Parasitism

II. MYRMECOPHILY (Ants as Hosts)
- *1. Persecuted Intruders (Synechthrans)
- 2. Indifferently Tolerated Guests (Synocketes)
- 3. Mess-mates (Commensals)
- 4. True Guests (Symphiles)
- 5. External Parasites (Ectoparasites)
- 6. Internal Parasites (Entoparasites)

III. TROPHOBIOSIS (Relations of Ants to Phytophthora, etc.)

IV. PHYTOPHILY (Relations of Ants to Plants)

The great armies of the nomadic legionary ants to which I alluded in my previous lecture often attack the nests of other ants and carry away and devour all their larvæ and pupæ. This is, of course, pure predatism and is not included in the list because it is hardly a true interspecific association. This is obviously prevented by the itinerant and highly carnivorous behavior of the plunderers. In the compound nests, however, the colonies of the two species occupy stationary nests which are so close together that their galleries may interdigitate or intercommunicate and permit one of the species to enter the nest of the other. Different ant colonies even of the same species are so hostile that their mere existence in such contiguity implies that one of the species is to some extent exploiting the other. That the manner of exploitation differs in different ants will be seen from the following brief account of the various known types of compound nests:

(1) Certain small but aggressive ants, which secure at least a portion of their sustenance by waylaying the foraging workers of another species and snatching away their food, deserve the name of brigands. Such ants naturally make their nests near those of the species they plunder. Thus *Dorymyrmex pyramicus* in our southwestern states often constructs its nests in the clearing surrounding or even on the large mounds of harvesting ants of the genus Pogonomyrmex (Fig. 79).

(2) In cases of what I call "thievery" the exploitation is more

FIG. 79
Mound of agricultural ant (*Pogonomyrmex occidentalis*) bearing a crater (at *a*) of a small brigand ant (*Dorymyrmex pyramicus*).

subtle and efficient. The thief-ants, all of which are subterranean and have very small workers, nest in the earthen walls of populous ant or termite nests, much as the little red house ant (*Monomorium pharaonis*) nests in the walls of our dwellings. The chambers of the two nests are connected by extremely tenuous galleries, excavated, of course, by the thief-ants and permitting them to invade the nests and feed on the brood of their large neighbors, but preventing the latter from entering the nests of the robbers, who are either ignored or overlooked on account of their diminutive size, and therefore carry on their depredations unhindered. The abundance of food which they thus secure enables them to rear very large queens and males, but the workers themselves are condemned to perpetual dwarfishness by their criminal mode of life. The most remarkable thief-ants are found in the large termite nests of the tropics, and the conditions described attain their most extreme expression in the genus Carebara. The workers are minute, pale yellow and blind, the queens and males deeply colored and several thousand times as large as the workers. Arnold has recently suggested that these extraordinary differences in size must make it impossible for the young queen to feed her first brood of workers and hence to establish her formicary in the typical independent manner of other ants. For this reason, when she leaves the parental nest to take her nuptial flight, she carries, attached by their mandibles to the tufted hairs on her feet, several workers, which thus accompany her till she has made her cell in some termite mound, and then take charge of rearing her first brood. On reading Arnold's account I examined a number of females and males of the Ethiopian *Carebara vidua* in my collection and at once found the minute workers attached as he describes. The accompanying sketch (Fig. 80) shows one of the queens carrying two workers. These, of course, also attach themselves to the males that leave the nest at the same time, but as they do not accompany the nest-founding queens and die just after mating, the workers that happen to choose air-planes of the wrong sex also perish.

(3) What, for lack of a better term, I have called "neighborliness," is a very common relationship between two, or more rarely three or even four species of ants living in nests, often with interdigitating but never with intercommunicating galleries, under the same stone or in the same log. Usually the ants of the different colonies, when they happen to meet, are more or less hostile. If one of the species is small and weak it undoubtedly derives some protection from merely living near a large and powerful neighbor, or the feebler may feed to some extent on the refuse of the larger

FIG. 80

Winged queen of *Carebara vidua* carrying the minute blind workers of her own species attached to her tarsal hairs.

form. When both species are large and aggressive they may perhaps find it advantageous to present a combined hostile front to the attacks of other ants.

(4) What Forel calls "parabiosis," a word I have translated as "tutelage," seems to be a more definite relation of mutual or unilateral protection. In a typical case which I recently observed in British Guiana, we have two species, a small black Crematogaster (*C. parabiotica*) and a large brown Camponotus (*C. femoratus*) together inhabiting a large ball of earth which they build up around the branch of a tree. In this ball, which Ule calls an "ant-garden," because it supports numerous epiphytes, the Crematogaster inhabits the superficial, the Camponotus the central portions. When it is slightly disturbed the little black ants rush out to attack the intruder, but a more serious disturbance

of the nest at once brings out the battalions of the much larger and extremely vicious brown species. The Crematogaster seem therefore to act as a skirmishing line for the Camponotus. Though the galleries of both species open freely into one another, and though the workers of both forage in long common files on the surrounding vegetation, they nevertheless keep their broods rigidly separated. The tutelary or parabiotic relation is evidently more mutualistic or cooperative than any of the foregoing cases of compound nests.

(5) An interesting series of small species includes the "guest ants" which live in still more intimate relations with other species. One of the best examples is *Leptothorax emersoni* which I first found many years ago associated with the considerably larger *Myrmica canadensis* in bog-like situations on our higher New England hills. The Leptothorax inhabit small chambers at the surface of the Myrmica nest and connect them by means of tenuous galleries with the chambers of their neighbors. The Leptothorax workers spend much of their time in the Myrmica nest where they mount the backs of the workers and assiduously lick their bodies and especially their heads and mouthparts. The Myrmicas seem greatly to enjoy this performance and from time to time reward their little guests with a droplet of regurgitated food. But while the Leptothorax arrogate to themselves the right to mingle freely with the Myrmicas and to flatter them into regurgitation, they resent the intrusion of the Myrmicas into their own habitations and insist on bringing up their own brood in perfect seclusion. Under natural conditions the Leptothorax are never seen to take any food, except from the surfaces and crops of their hosts, but if kept for some time by themselves in an artificial nest, they learn to eat honey and insects like other ants. And if both species are kept together in a glass nest without earth and therefore without materials for making separate chambers, the Leptothorax eventually though very reluctantly permit the Myrmicas to mingle the broods of both species and a true mixed colony is formed.

The ants that live in the various compound nests are not closely allied but belong to different genera or even subfamilies, a fact which may help to explain why they occupy separate nests and do not bring up their broods in common, for the rearing of the brood is a very delicate operation and would be apt to differ considerably in unrelated species. We may therefore be prepared to find that mixed colonies are formed only by closely allied species, *i. e.*, either by those belonging to the same genus or to closely allied genera, and this proves to be the case. But before considering the

various types of mixed colonies, two facts must be emphasized: First, many ants are fond of kidnapping the larvæ and pupæ belonging to other colonies of their own or allied species. Frequently these kidnapped young are devoured, but in well-nourished colonies they may be permitted to complete their development and the emerging workers may be adopted as *bona fidè* members of the colony, even if they belong to a different species. It is therefore possible to produce a mixed colony artificially by giving a colony the mature brood of some other species. In this manner Miss Fielde succeeded in inducing species belonging even to very different subfamilies to live together in perfect amity. It is also interesting to observe that ants thus reared in the colony of an alien species may be very hostile to their own sisters that have been left to grow up in the parental nest. Second, the mixed colonies found in nature are not in the first instance produced by a mere kidnapping of the brood of an alien species, but by the young queen of a parasitic species, that is unable to start a colony independently, invading the nest of another species, which then becomes the host. The behavior of the invading parasite and the

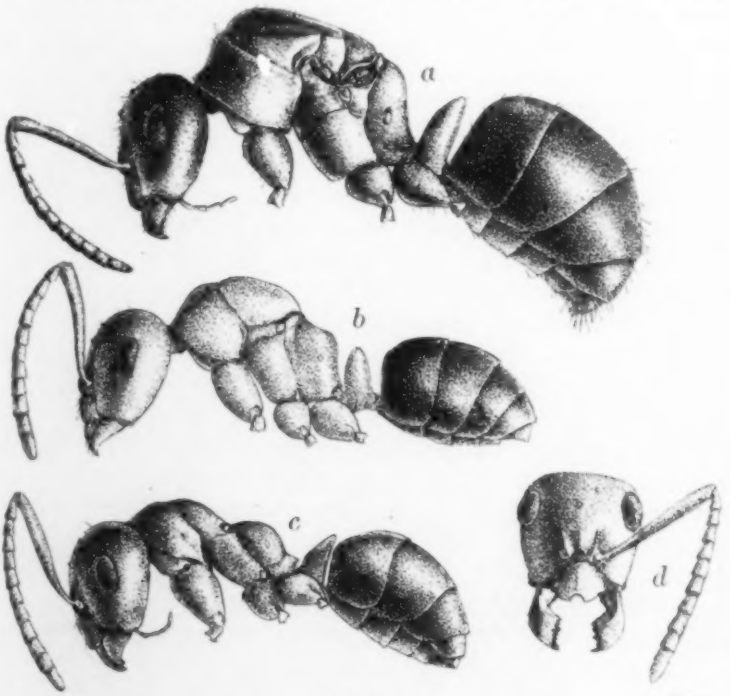

FIG. 81

Blood-red slave-maker (*Formica sanguinea*) in profile. *a*, Queen, with wings and legs removed; *b*, pseudogyne; *c*, worker; *d*, head of same from above, showing the characteristic notch in the clypeus.

host colony differ in different species, but in nearly all the observed cases the host queen, if present, is eventually killed and her place is taken by the alien intruder. Since the queen ant is really the reproductive organ of the colony considered as a superorganism, the host colony may be said to be castrated and its sterile worker personnel is constrained to devote all its energies to rearing the brood which is forthwith produced by the fecund parasite. With these general statements in mind we may turn to the three types of mixed colonies, those of the slave-makers, the temporary and permanent social parasites:

(1) The peculiar phenomena known as slavery, or dulosis, which occur in two genera of Formicinæ, Formica and Polyergus, and two genera of Myrmicinæ, Strongylognathus and Harpagoxenus, represent three phylogenetic stages, a primitive stage in *Formica sanguinea*, a culminating stage in Polygergus and a degenerate or evanescent stage in Strongylognathus and Harpagoxenus. The "blood-red slave maker," *F. sanguinea* (Fig. 81), is a common but rather local red ant, with black or brown gaster and is represented by numerous subspecies and varieties ranging over northern Europe, Asia and North America. It can be readily distinguished from the other species of the genus, at least in the Old World and the eastern United States, by the pronounced notch in the clypeus or small shield at the anterior end of the head. The worker and queen look as if they were hare-lipped. *Sanguinea* is one of the most intelligent of ants and therefore one of the most interesting to keep in artificial nests. Its habits were first studied more than a century ago by Pierre Huber, the son of the blind François Huber, and have ever since commanded the attention of myrmecologists, because its armies of workers make periodical forays on the colonies of the common black *Formica fusca*, carry the worker larvæ and pupæ into their nest and permit many of them to emerge and become members of their colony. Thus the colony is mixed, and the black individuals, on account of their color and provenience, have been called "slaves." It is evident, however, that this term is inappropriate, for a slave is "a man who is the property of another, politically and socially at a lower level than the mass of the people, and performing compulsory labor" (Nieboer), and none of these distinctions applies to the *fusca* workers in the *sanguinea* nest. They are more properly called "auxiliaries" (Hilfsameisen), but I shall use the old term on account of its brevity. At least one of the subspecies of *sanguinea* (*aserva*) does not make slaves, and the colonies of some of the other forms give up the habit after a time, for the *sanguinea* colony, when once established, is quite able to lead an independent

life. Darwin and others offered various explanations of the peculiar slave-making habit of *sanguinea*, but its meaning remained obscure till 1904 when I found that it had its origin in the behavior of the young queen. She is quite unable to found a colony independently and therefore, after her marriage flight, may adopt one of three courses: she may return to the nest in which she was reared or enter some other *sanguinea* nest, or she may invade a nest of *F. fusca*. As the first and second courses are sometimes adopted by other ants and do not lead to the formation of mixed colonies, they need no further consideration in this place and we may confine our attention to the last. As soon as the *sanguinea* queen invades a *fusca* colony, she becomes greatly excited and interested in the brood, seizes and collects in a small pile as many pupæ as she can snatch up and mounts guard over them. She slays any *fusca* workers that are bold enough to attempt to regain their property and is therefore soon left in undisputed possession of her plunder. Eventually *fusca* workers emerge from the cocoons and at once assume a friendly attitude towards the queen, feed her by regurgitation and behave towards her as if she were their own mother. She begins to lay eggs and the resulting larvæ are fed and reared by the black workers, so that when the *sanguinea* emerge a mixed colony is established. These workers show that they have inherited their mother's proclivities by kidnapping the brood of neighboring *fusca* colonies, but they do this as an army and carry the *fusca* brood to their nest. In some colonies, as I have stated, this kidnapping or slave-making proclivity may disappear after a time, and in *aserva* it seems to disappear very early or perhaps is not even inherited by the workers. In such cases, therefore, the personnel of old colonies may be made up entirely of *sanguinea* after the batch of *fusca* workers kidnapped and reared by the queen has died of old age. It is evident that slavery is at bottom a form of predatism and has its origin in the inability of the young queen to establish a colony without the aid of workers. Unlike the great majority of ant-queens, she has been unable to store enough food in her body to stand the strain of long fasting and nourishing her first brood. In another sense she is, of course, a parasite and the *fusca* workers represent the host. Owing to the fact that the colony may eventually cease to increase its worker personnel by the kidnapping of *fusca* brood, we may call this type of slavery temporary, acute or facultative.

The species of Polyergus, or "amazons," as they were called by Pierre Huber, have much the same distribution as *sanguinea* and have the same species of Formica as slaves, but their method of securing the latter is more highly perfected. The amazons

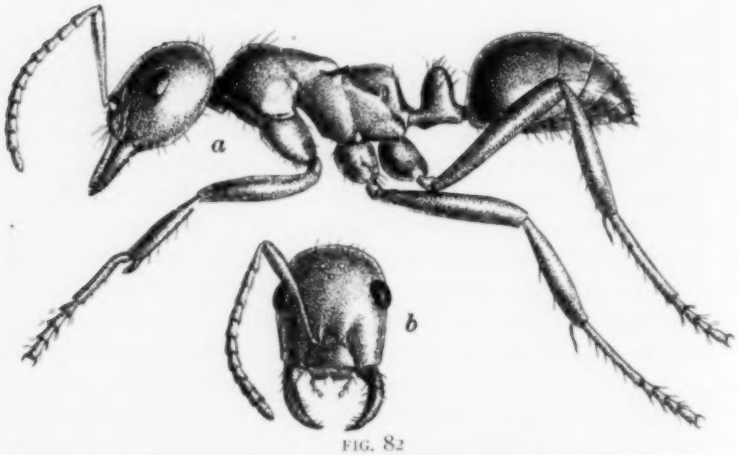

FIG. 82

a, Worker of *Polyergus lucidus*, the "shining amazon," a permanent slave-maker of the Eastern United States; *b*, head of same, showing the sickle-shaped mandibles.

are very beautiful red ants (except the Japanese *P. samurai*, which is black), and their mandibles are slender and sickle-shaped and perfectly adapted to fighting but of no use for digging in the earth or capturing food (Fig. 82). Hence these insects are unable to make nests or even to feed themselves or care for their own young, but are absolutely dependent on their slaves. Like *sanguinea*, the amazons make periodical forays, which for some unknown reason are always carried out in the afternoon, but their armies show a more perfected tactical organization and the subjugation and plundering of the *fusca* colonies are effected with much greater dispatch and precision—one might say with the most consummate *éclat*. At the approach of the amazons the *fusca*

FIG. 83

a, Worker of *Strongylognathus testaceus*, a degenerate slave-maker of Europe; *b*, head of female of same; *c*, head of worker of *S. huberi*, an allied species; *d*, worker of the pavement ant (*Tetramorium caespitum*), the host of the species of Strongylognathus.

workers usually flee in dismay, but if they offer any resistance the amazons pierce their heads with the sickle-shaped mandibles. The young on emerging from the kidnapped pupæ excavate the nest, feed the Polyergus and bring up their brood but do not accompany the armies on their raids. The initial stages in founding the colony have been studied by Emery, who found that the young Polyergus queen secures adoption in some small, weak *fusca* colony after killing its queen by piercing her head. She then produces her brood which will later make the slave-raids on the *fusca* colonies. Since this raiding proclivity never lapses even in old colonies, Polyergus is to be regarded as a chronic, or obligatory slave-maker. An amazon crimson on a field sable with the device "*stultus sed pugnax*" might be an appropriate coat-of-arms for some of the military castes that have flourished during the course of human history.

In Europe there are several species of the interesting genus Strongylognathus (Fig. 83*a-c*), which have sickle-shaped mandibles like Polyergus and always live in the colonies of the common pavement ant, *Tetramorium caespitum* (Fig. 83*d*). Our fragmentary knowledge indicates that we have here some of the degenerate or evanescent stages of slavery. The workers of *S. rehbinderi* and *huberi* seem still to make forays on Tetramorium colonies and to carry home their brood, and Kutter has recently shown that *S. alpinus*, a form I discovered some years ago near the head-waters of the Visp, within sight of the Matterhorn, makes nocturnal slave raids and is accompanied by its slaves, which do most of the fighting and carry home the brood of their own species. In this case the slaves are really the masters and seem to use the Strongylognathus merely as a means of disconcerting or terrifying the colonies of *cæspitum* whose brood they are bent on kidnapping. Finally, *S. testaceus*, the best-known species of the genus, no longer makes forays and is tending to lose its worker caste. Wasmann, Mrázek, Forel and I have found that colonies of *cæspitum* infested by this species may retain the host queen. In order to establish her colony, therefore, the young *testaceus* queen probably associates herself with a young, nest-founding *cæspitum* queen. In the mixed colonies of other species of Strongylognathus the host queen appears to be eliminated as in the colonies of *sanguinea* and Polyergus.

(2) In 1904 I detected another method of forming mixed colonies, which I called temporary, although I might have called it acute social parasitism. It is practiced by a number of ants, especially by several North American species of Formica that have unusual queens. In some species they are peculiarly colored or

furnished with long yellow hairs, in others they are extremely small, smaller even than the largest workers (Fig. 84). The young queen of these ants enters the nest of another Formica belonging to the *fusca* or *pallide-fulva* group and is very apt to be adopted, probably on account of her smaller size or other physical attractions. The fate of the host queen in such invaded nests has not been ascertained but she is probably killed by her own workers. The parasite then proceeds to produce her brood, which is reared by the host workers, and a mixed colony results. As there is no inclination on the part of the queen's offspring to plunder other nests of the host species, and as all the host workers die off in the course of a few years, a pure colony of the parasitic species is left behind and may grow to be very populous and aggressive, without showing any signs of its parasitic origin—a beautiful analogue of some human institutions, which after starting in humble and cring-

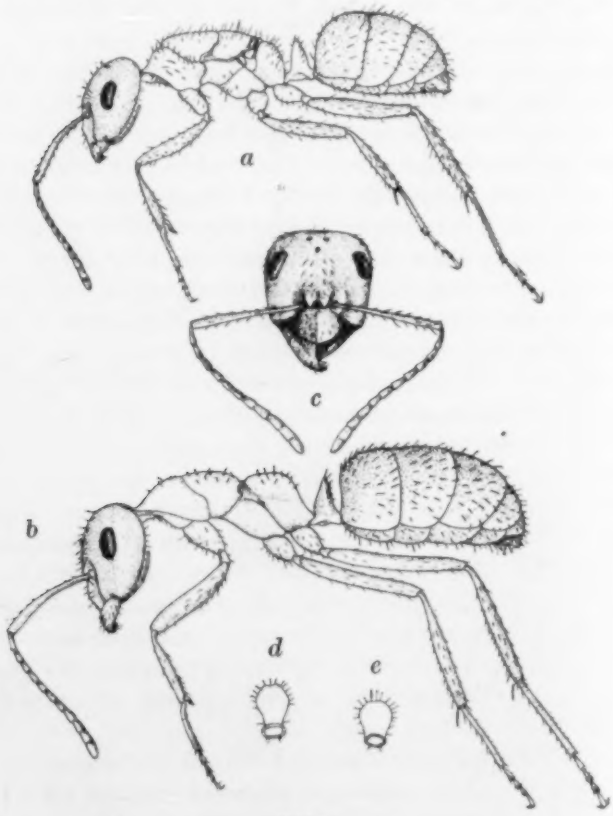

FIG. 84

A temporary parasite (*Formica microgyna*). *a*, queen, with wings removed; *b*, large worker drawn to same scale; *c*, head of same; *d* and *e*, petiole of worker and queen seen from behind.

ing parasitism have come to acquire during the centuries a most exuberant and insolent domination. Our common mound-building ant (*Formica exsectoides*) is one of these successful temporary parasites which starts its opulent colonies with the aid of the ubiquitous *F. fusca* var. *subsericea*. Since my observations were published many European Formicas, including the well-known mound-building *rufa*, and ants of several other genera (Lasius, Bothriomyrmex, Crematojaster, etc.) in various parts of the world have been found to be temporary social parasites. One of the most interesting of these is the Dolichoderine *Bothriomyrmex decapitans* which Santschi observed in Tunis. The young queen, on descending from her marriage flight, wanders about on the ground till she finds the nest of a *Tapinoma nigerrimum* colony, when she permits herself to be seized and "arrested" by its workers. These then proceed to drag her into their burrow by her legs and antennæ. After entering the nest the parasite may be attacked from time to time by the workers, but she takes refuge on the brood or on the back of the larger Tapinoma queen. In either of these positions she seems to be quite immune from attack, probably because her own odor is overlaid by that of the brood or the host queen. Santschi observed that the parasite often spends long hours on the back of the Tapinoma queen and that while in this position she busies herself with sawing off the head of her host! By the time she has accomplished this cruel feat, she has acquired the nest-odor and is adopted by the Tapinoma workers in the place of their unfortunate mother. The parasite thereupon proceeds to keep them busy bringing up her brood. They eventually die of old age and the nest then becomes the property of a thriving, pure colony of *Bothriomyrmex decapitans*.

(3) There are more than a dozen genera of ants from various parts of the world, which may be classed as permanent, or chronic social parasites. They have all completely lost the worker caste so that in this respect they closely resemble the parasites among the social wasps and bees. The young queens enter the nests of other ants and secure adoption, like the queens of the temporary social parasites. The host queen seems to be regularly assassinated by her own workers. At least this has been observed by Santschi in the case of *Wheeleriella santschii*, which lives in the nests of the common North African *Monomorium salomonis*. After fecundation the *Wheeleriella* queen roams about over the surface of the soil in search of a Monomorium nest. When near the entrance of one of them she is "arrested," to use Santschi's expression, by a band of Monomorium workers, which tug at her legs and antennæ and draw her into the galleries. Sometimes she may be

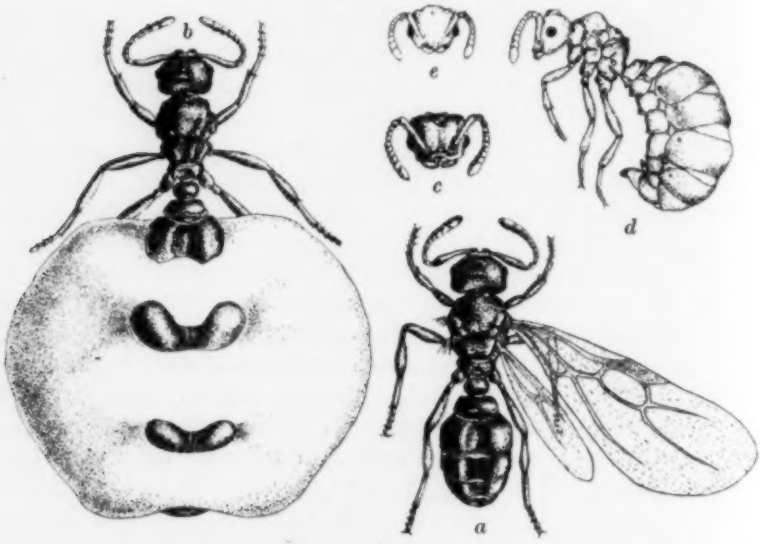

FIG. 85

A workerless, degenerate, permanent social parasite (*Anergates atratulus*) of Europe. *a*, virgin queen; *b*, old, egg-laying queen with enlarged gaster; *c*, head of same from front; *d*, male, which is wingless and pupoidal; *e*, head of same.

seen to dart suddenly into the entrance of her own accord and is arrested within the nest. There are no signs of anger on the part of the Monomorium, and she is soon permitted to move about the galleries unmolested. The workers then begin to feed and adopt her and in the course of a few days she lays her first eggs, which are accepted and cared for by the host. The parasite pays no attention to the much larger Monomorium queen, but the latter is eventually assassinated by her own workers. Other species, like the famous *Anergates atratulus* (Fig. 85) of Europe and the recently discovered *Anergatides kohli* of the Congo, are much more highly modified and represent the last stages of parasitic degeneration. In the former, which lives with *Tetramorium cæspitum*, the queen is small and winged (Fig. 85*a*), but after deälation and adoption her gaster swells enormously with eggs till she resembles an old termite queen (Fig. 85*b*). The male (Fig. 85*d*) is wingless and pupa-like and unable to leave the nest so that mating takes place between brothers and sisters ("adelphogamy" of Forel). The conditions in Anergatides, which is a parasite of *Pheidole melancholica*, are somewhat similar. In the workerless parasites the offspring of the intrusive queen are, of course, all males and females and are produced during the life-time of the host workers. The colonies are therefore mixed throughout their existence which is necessarily terminated by the death of the host.

While all myrmecologists now agree in recognizing the three types of social parasitism and their origin in the behavior of the young queens, there is still disagreement in regard to their phylogenetic derivation. I at first believed that they had all had their inception in the passive adoption of insufficiently endowed, young queens by colonies of their own species, and Wasmann has consistently adhered to this view. Emery and Viehmeyer, however, see in the aggressive, predatory behavior of the *sanguinea* queen a stage from which temporary and permanent social parasitism may be more naturally derived. I am now inclined to believe that these investigators are nearer the truth and that the adoption of queens by colonies of their own species is a distinct phenomenon, which may readily lead to the formation of new colonies by a kind of swarming, analogous to that of many social bees and wasps, but not to the series of parasitic developments which we have been considering.

All the parasitic ants are rare or local. The permanent, or chronic social parasites, especially, are so very scarce that they must be on the very verge of extinction—a fact which shows that parasitism, so far as the race is concerned, is anything but a promising or profitable business. But even the individual parasite buys its rare successes very dearly, for it must often run the gauntlet of great resistance and animosity on the part of a too healthy host and must at the same time carefully avoid seriously injuring that host and thus bringing about its own destruction. Parasitism in the queen ant may, indeed, be regarded as a kind of compensation or overcompensation for her inability to rear a brood of workers. One is reminded of the overcompensations (megalomania) resorted

PERMANENT SOCIAL PARASITES (ANTS WITHOUT WORKERS)

PARASITES	HOSTS	HABITAT	ANCESTRAL GENUS
Sympheidole elecebra	*Pheidole ceres*	Nearctic	Pheidole
Epipheidole inquilina	*Pheidole ceres*	Nearctic	Pheidole
Parapheidole belti	(?) *Pheidole sp.*	Malagasy	Pheidole
Sifolinia laurœ	(?) *Pheidole sp.*	Palearctic	Pheidole
Anergatides kohli	*Pheidole melancholica*	Ethiopian	Pheidole
Wheeleriella santschii	*Monomorium salomonis*	Palearctic	Monomorium
Wheeleriella adulatrix	*Monomorium subnitidum*	Palearctic	Monomorium
Wheeleriella wrougtoni	*Monomorium indicum*	Palearctic	Monomorium
Epœcus pergandei	*Monomorium minimum*	Nearctic	Monomorium
Epizenus andrei	*Monomorium venustum*	Palearctic	Monomorium
Epizenus biroi	*Monomorium creticum*	Palearctic	Monomorium
Myrmica myrmoxena	*Myrmica lobicornis*	Palearctic	Myrmica
Hagioxenus schmitzi	*Tapinoma erraticum*	Palearctic	Monomorium
Anergates atratulus	*Tetramorium cæspitum*	Palearctic	(?) Tetramorium
Pseudoatta argentina	(?) *Mœllerius balzani*	Neotropical	Mœllerius
Plagiolepis nuptialis	*Plagiolepis custodiens*	Ethiopian	Plagiolepis

to by some human being with pronounced inferiority complexes. Was it an inkling of this that led the ancients to make Hercules the tutelary deity of parasites? That the parasitic queen's inability has been acquired and fixed during the past history of the species is suggested by the singularly close genetic relations of the parasites to their hosts. In the great majority of cases, as indicated in the accompanying list, the parasite belongs either to the same genus as its host or to a genus descended from that of its host. This is equally clear from detailed lists of the other parasitic ants, wasps and bees and shows that the parasite originally led an independent life but took to exploiting some common, allied species of the same genus. Probably the exploitation was at first predatory as it still is in certain Psammocharid wasps and *Formica sanguinea*, because food was more expeditiously secured by such tactics. In the course of time the parasite's adaptations to its host became increasingly refined and were reflected in its structure as generic distinctions, as we see, *e. g.*, in the species of Polyergus, which are obviously modified Formicas. The descent to Avernus became steeper and more slippery, as the parasite, yielding to inertia, became chronically and abjectly dependent on its host and condemned itself to physiological and numerical inferiority ("misère physiologique"). The next stage is extinction, after a longer or shorter period of hopeless specialization ("degeneration"). This or a very similar story has been so often repeated in all the classes of the animal and plant kingdoms that the number of forms which during geological time have descended to the *limbus parasitorum* must be considerable.

Having considered the ants as parasites and hosts of one another, we may now turn to the cases in which they act as the hosts of insects belonging to very different orders, the myrmecophiles, or ant- guests. Here we enter on a vast and very intricate subject to which I shall be unable to do justice in the short time at my disposal. Fully 2,000 species of myrmecophiles have been described, and no doubt the number will be more than doubled when the nests of the many species of tropical ants have been carefully explored. The myrmecophiles include not only members of nearly all the different orders of insects but also many spiders, mites, millipeds and land-crustaceans—a weird, one might almost say demoniacal, horde of creatures, which have been induced to live in more or less intimate and maleficent relations with the ants by the obvious advantages of the association. Ant nests furnish admirable hiding or lurking places and are at night and during the winter months somewhat warmer than the surrounding soil. They often contain quantities of food or refuse, and the helpless brood,

callow and injured ants may be stealthily devoured. Furthermore, the ants may be wheedled into adopting and feeding alien insects, as if they were their own young or ants of the same species. All the forms of exploitation, therefore, from predatism, adoption and domestication to external and internal parasitism have been developed by the myrmecophiles. It may be said that these creatures have searched out and taken advantage of every vulnerable point in the ant's structure and behavior, just as every human idiosyncrasy, frailty and virtue has been exploited by some cunning human parasite.

There are two reasons why we must consider the myrmecophiles in these lectures. First, many of them live only with particular ants and really form a constituent though not an essential part of their colonies, for although they are not present in all colonies, they can not exist apart from the ants except while migrating from one nest to another. They are, in fact, a more integral component

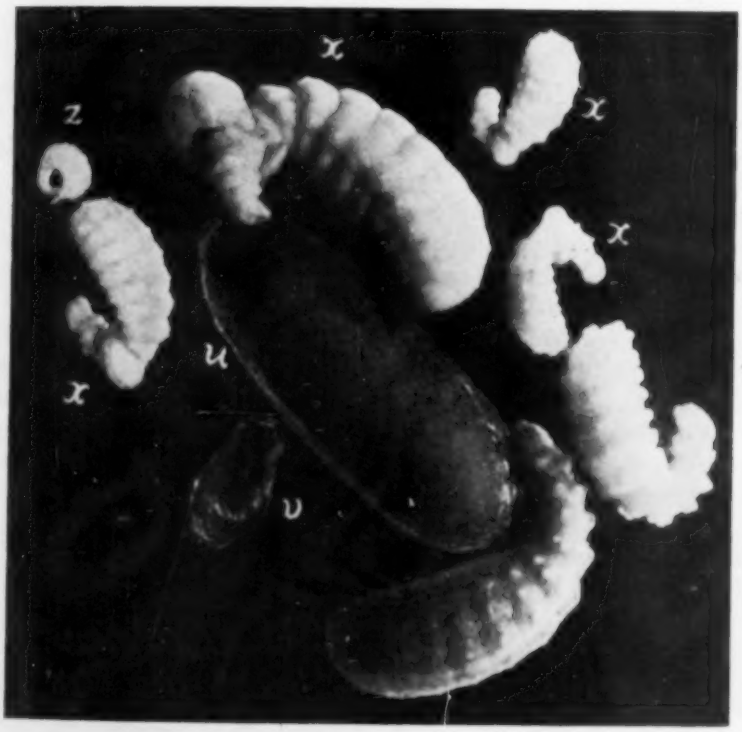

FIG. 86

Larvæ and pupæ of a ponerine ant (*Pachycondyla montezumia*) and its commensal (*Metopina pachycondylae*). The Pachycondyla larvæ marked *x* have each a Metopina larva around the neck; *z*, isolated Metopina larva; *v*, Metopina puparium; *u*, cocoon of Pachycondyla.

of the colony in which they occur than are the domestic animals in the human community. Many of our domestic animals are still able to return to an independent, feral life, but this is impossible for the more typical and highly specialized ant-guests. Second, the ant-guests afford a very striking, indirect or pathological demonstration of the extraordinary intensity of the brood-nursing propensities of ants. Any insect possessed of the glandular attractions, which I shall presently describe, can induce the ants to adopt, feed and care for it and thus become a member of the colony, just as an attractive and apparently well-behaved foreigner can secure naturalization and nourishment in any human community. But the procedure among the ants is more striking, because the foreigners are so very foreign, that is, belong to such alien and heterogeneous groups. Were we to behave in an analogous manner we should live in a truly Alice-in-Wonderland society. We should delight in keeping porcupines, alligators, lobsters, etc., in our homes, insist on their sitting down to table with us and feed them so solicitously with spoon-victuals that our children would either perish of neglect or grow up as hopeless rhachitics.

Although every species of myrmecophile has its own methods of securing food and lodgings in the ant nest I shall describe only a few examples to illustrate the exploitation of the trophallactic habit.

(1) There are probably several myrmecophiles that steal the food given to the larva, but the only case that has been adequately described is the larva of a small fly, *Metopina pachycondylæ*, which I found many years ago in Texas infesting the nests of a Ponerine ant, *Pachycondyla montezumia* (Fig. 86). This ant feeds its larvæ in a very primitive manner with pieces of insects and thus exposes itself to the inroads of the Metopina. Its small larva clings to the neck of the ant larva by means of a sucker-like posterior end and encircles its host like a collar. Whenever the ant larva is fed by the workers with pieces of insect placed on its trough-like ventral

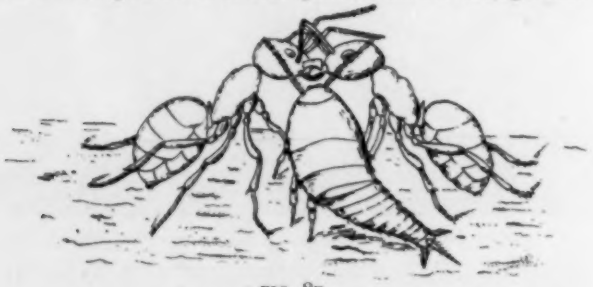

FIG. 87

Atelura formicaria about to snatch the droplet of food that is being regurgitated by one *Lasius mixtus* worker to another. (After C. Janet.)

surface, within reach of its mouthparts, the larval Metopina uncoils its body and partakes of the feast; and when the ant larva finally spins its cocoon it also encloses the Metopina larva within the silken web. The commensal, however, moves to the caudal end of its host and forms a small flattened puparium which is applied to the wall of the cocoon. This is obviously an adaptation for preventing injury from the jaws of the worker ants when the cocoon is being opened and the callow extracted from its anterior end. The ant hatches before the Metopina and the empty cocoon, with the puparium concealed in its posterior pole, is carried to the refuse heap. Here the fly emerges and escapes from the cocoon by the opening through which its host emerged. The Metopina consumes so little food and is so considerate of its host that it can hardly be said to produce any injurious effect on the colony; at any rate the larvæ which have borne commensals develop into perfectly normal workers. The ants clean the commensals when they are cleaning their own progeny and show no signs of being aware of their presence in the nest.

(2) *Lepismina* (*Atelura*) *formicaria* (Fig. 87) is a small, primi-

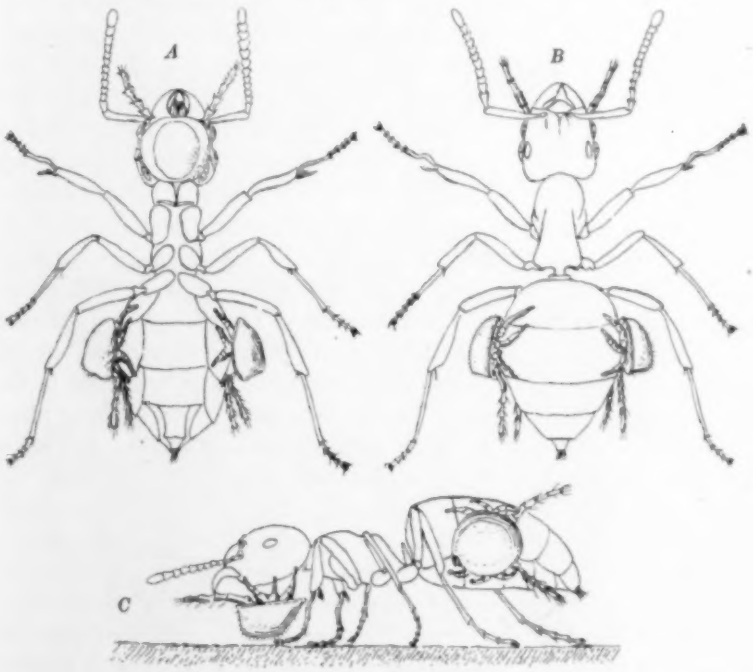

FIG. 88

Lasius mixtus worker carrying three symmetrically oriented mites (*Antennophorus pubescens*). *A*, ventral; *B*, dorsal; *C*, lateral view. (After C. Janet.)

tive insect which lives in the nests of *Lasius mixtus*. Its body tapers rapidly behind and is covered with slippery scales so that it is not easily caught by the ants. It is, moreover, extremely agile and circumspect, because it has not succeeded in ingratiating itself with its hosts. Janet, after providing a colony of *Lasius mixtus* with honey, was able to make the following observations on the behavior of the insect: "From the instant that the first foragers returned to the nest, the Lepismina showed by their excitement that they perceived the odor of honey. Soon a considerable number of ants were grouped in couples for the purpose of regurgitating. They elevated their bodies slightly and often raised their fore legs, thus leaving a vacant space under their heads. As soon as a Lepismina came near such a couple, it thrust itself into the space, raised its head, suddenly snapped up the droplet that was passing in front of it and made off at once as if to escape merited pursuit. But the ants standing face to face are not free enough in their movements even to threaten the audacious thief, who forthwith proceeds to take toll from another couple and continues these tactics till his appetite is appeased."

(3) A more subtle method of obtaining regurgitated food is adopted by the large mites of the genus Antennophorus (Fig. 88), which have been studied by Janet, Wasmann, Karawaiew and myself. These mites, which have conspicuously long fore legs and attach themselves to the bodies of the workers, whether present in odd or even number, always orient themselves in a symmetrical position with respect to their host. When only one Antennophorus is present it clings to the gula, or chin of the ant, with its fore legs directed towards the ant's mouthparts. When two are present, there is one on each side of the head or one on each side of the gaster; in the former case the antenniform appendages are directed towards the anterior, in the latter towards the posterior end of the ant's body. When there are three mites, one attaches itself to the chin and the two others to the sides of the gaster. Four place themselves in pairs on the sides of the head and gaster. If six are present, which rarely happens, four are arranged in pairs on the sides of the head and gaster while of the two remaining individuals, one attaches itself to the chin, the other to the mid-dorsal surface of the gaster. Janet believes that these symmetrical arrangements are for the purpose of balancing the burden and thus making it easier for the ant to carry. When attached to the head the mite obtains its food by drinking the regurgitated droplet as it is being passed to or from the mouthparts of the host, or it titillates the ant with its antenniform legs and induces her to regurgitate for its special benefit. The mites attached to the gaster obtain their

food by stroking other ants in the vicinity or by reaching out and partaking of the droplets as they pass from one ant to another. The ants try to rid themselves of the parasites when they first attach themselves, but after they have taken up their definitive, symmetrical positions, they seem to be tolerated with indifference.

Most of the species of Antennophorus have been described from Europe, but I have found two species (*donisthorpei* and *wasmanni*) rather common near the Arnold Arboretum in Boston. They live in essentially the same manner as the European Antennophori with our small yellow ants of the genus Lasius, and its subgenus Acanthomyops. All these Lasii are hypogæic and devote themselves to attending snow-white plant-lice and mealy-bugs on the roots of our forest trees, and since the mites occur only with these ants it would seem that they, the plant-lice, the mealy-bugs, the mites and the forest trees are all so many members of a peculiar, subterranean association, or biocoenose. The plant-lice and mealy-bugs pump the juices out of the plants and pass on to the soliciting ants the unassimilated portions in the form of honeydew, some of which the ants regurgitate to the mites that ask them for it by aping with their long, hairy forelegs the antennary movements of the hungry ants. In other words, the ants serve as cup-bearers, distributing to one another and to the indolent, sedentary Antennophori the nectar which the tapster plant-lice and mealy-bugs keep drawing from their vegetable hosts. Owing to this interesting biocoenotic arrangement the worker Lasii do not have to come to the surface of the ground to seek their food. The eyes of the

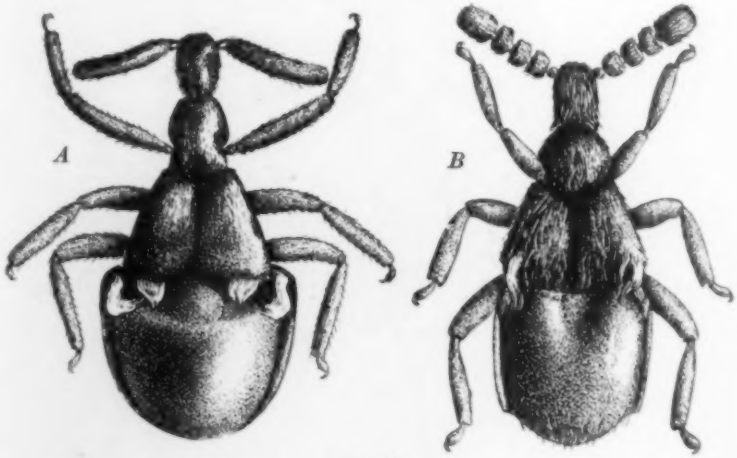

FIG. 89

A, Adranes lecontei of North America, and *B, Claviger testaceus* of Europe, two guest beetles, with golden yellow trichomes at the tips of their wing-cases and at the base of the abdomen.

workers have therefore become so minute that their visual powers must have nearly or quite disappeared. Perhaps we can best appreciate the relations of the ants to the mites if we fancy ourselves blind, condemned to live in dark cellars and continually occupied with pasturing and milking fat, sluggish cows, yielding quantities of strained honey instead of milk. Then let us suppose that occa-

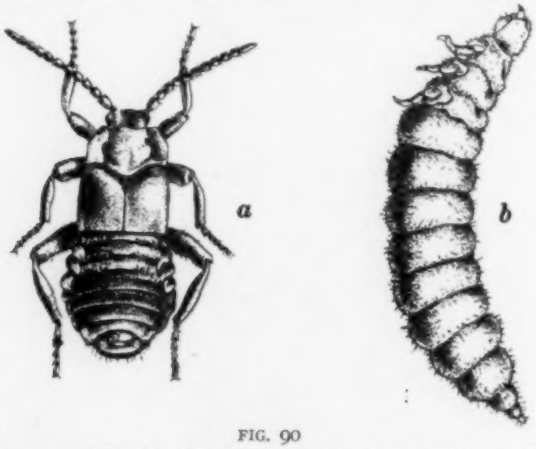

FIG. 90

a, A European guest-beetle (*Lomeschusa strumosa*) and *b*, its larva, which live with colonies of the blood-red slave-maker (*Formica sanguinea*).

FIG. 91

Xenodusa cava, a North American beetle which breeds in the nests of Formica during the summer and passes the winter in the nests of Camponotus. Note the tufts of trichomes along the sides of the abdomen.

sionally there alighted on our cheeks or backs small creatures which, by placing themselves in positions symmetrical to the median longitudinal axis of our bodies, took great care not to annoy us, and stretched forth to us from time to time small, soft hands, like those of our friends, begging for a little of the honey, should we not under the circumstances treat these little Old Men of the Sea with much lenity and even with something akin to affection?

(4) The behavior of the myrmecophiles I have been considering is simple and transparent compared with that of the true ant-guests or symphiles, which are really the *élite* of all the insects that live in ant colonies. They comprise several hundred species of beetles belonging to a number of natural families but showing a very singular, convergent agreement in certain characters, such as a deep, oily red color and peculiar tufts of golden yellow hairs, or trichomes on various parts of their bodies (Fig. 89). Their antennæ and mouth-parts, too, are in many cases peculiarly modified, the former for soliciting, the latter for receiving regurgitated food. The trichomes surround the openings of singular glands, the aromatic, volatile secretions of which flow along the hairs and are licked off by the ants. So inordinately fond are the ants of these secretions that they cherish the beetles, feed them and carry them to safety when the nest is disturbed or to new nests when the old ones have to be abandoned. The beetles breed in the colonies and their larvæ are often treated with even greater solicitude than the ant larvæ.

FIG. 92

Worker of the blood-red slave-maker, *Formica sanguinea*, feeding its guest beetle, *Lomechusa strumosa*. (After H. K. Donisthorpe.)

Probably the most remarkable of these true guests are the Lomeschusini, which have been studied by Wasmann for more than 30 years. They belong to the rove-beetles, or Staphylinidæ and comprise only three genera: Lomeschusa (Fig. 90) and Atemeles, peculiar to Europe and Northern Asia, and Xenodusa (Fig. 91), known only from the United States and Mexico. The species of Atemeles and Xenodusa have two hosts, those of the former living during the summer and breeding in Formica colonies but hibernating in colonies of Myrmica, the latter also breeding with Formica but hibernating with our large carpenter ants of the genus Camponotus. Lomeschusa, on the other hand, has only one host, *Formica sanguinea*, with which it lives throughout the year. The adult beetles of all three genera look much alike. They have long, mobile antennæ, short wing-cases and a voluminous abdomen, which can be curled up over the thorax and is provided on each side above with a segmental series of beautiful golden trichomes. Atemeles and Xenodusa beg their food from the ants by stroking their cheeks with the fore feet. Their larvæ are active, have long legs and employ the same method as the beetles in persuading the ants to regurgitate. They also devour the defenseless Formica larvæ. The adult Lomeschusa is more passive in its behavior and uses its antennæ in soliciting food (Fig. 92). Its larvæ (Fig. 90*b*) have very short legs and are unable to run about but lie among the ant brood. They eat the brood but are also fed by regurgitation. In all probability they secrete fatty exudates which are greatly appreciated by the ants. At any rate, the ants seem to prefer the Lomechusa larvæ to their own, or perhaps regard them as unusually promising ant larvæ. In consequence of this infatuation the Lomechusa larvæ often destroy the greater part of the brood, so that in *sanguinea* colonies heavily infested with the parasites the queen larvæ develop abnormally. Either these larvæ are neglected, or the ants actually endeavor to convert them into workers, because they feel that this caste is inadequately represented in the colony. But whatever be the treatment of the queen larvæ, they develop into pathological adults, known as "pseudogynes" (Fig. 81*c*)—abortive creatures, resembling workers in size and in the shape of the head and gaster, but with a more voluminous and convex thorax, approaching that of the queen. They are paler than the normal workers and very lazy, cowardly and incompetent. Usually they constitute 5 to 7 per cent., less frequently 20 per cent. or more, of the personnel of an infested *sanguinea* colony. Their appearance in a nest indicates that the colony is in a diseased condition and on the road to extinction, as the result of Lomechusa infection. Similar pseudogynes are also

produced in the Formica colonies infested with Atemeles and Xenodusa, but not in the Myrmica and Camponotus colonies in which the beetles hibernate, because they do not breed among their winter hosts and can not therefore interfere with the normal development of their brood.

Such being the effect on the colonies that harbor the Lomechusini, one naturally inquires why the habit of rearing the parasites has not long since led to the extinction of the Formicas. This question has been partially answered by Wasmann. He finds that the ants treat the Lomechusa larvæ like their own, even when they are ready to pupate. *F. sanguinea*, like many other ants, buries its full-grown larvæ in the soil in order that they may spin their cocoons and pupate within them. After pupation the cocoons are unearthed, cleaned and stacked up in the chambers of the nest. Now the full-grown Lomechusa larvæ also need to be buried in order to pupate, though they do not spin cocoons, but they must not be unearthed after pupation, like the ant brood, or they perish. The ants, however, are utterly ignorant of these different developmental requirements and therefore unearth as many of the Lomechusa pupæ as they can find. Thus death in the guise of what might be called a regulatory Nemesis overtakes all except the few pupæ that have been overlooked by the ants, but these few suffice to insure the survival of the species. More recently Wasmann has claimed that *sanguinea* takes a particular liking to certain pairs of beetles and eliminates the less attractive individuals from the colony. Of course, this would still further tend to reduce the incidence of parasitism and its baneful effects on the host.

The behavior of *sanguinea* and Lomechusa has seemed to Wasmann so unique and extraordinary that he has used it on every occasion as furnishing brilliant proofs of the absence of intelligence in ants, of the impotence of natural selection, of the possession by *sanguinea* of a singular, innate Lomechusa-fostering instinct, and therefore of a new type of selection, which he calls "amical selection," and, finally, even of the Divine Wisdom in maintaining the equilibrium in nature. Being a very accomplished Jesuit he has devoted many hundred pages and much scholastic casuistry to these "proofs." To the biologist who is under no compulsion to make his conclusions square with the philosophy of St. Thomas Aquinas, the behavior of *sanguinea* appears in a very different light, as a brilliant example of the perversion of appetites. Escherich has compared the infatuation of the Lomechusa-cherishing *sanguinea* with alcoholism in the human species. It might also be compared with a cat's infatuation with cat-nip, and the rearing of the Lomechusa larvæ by the ants would

seem to be due to the same kind of instinct perversion that we observe in the birds that rear cuckoos, the occasional cat that rears a puppy or the hen that adopts kittens. It would seem to be no more necessary to postulate a special Lomechusa-rearing instinct in *sanguinea* than a special ice-cream instinct in our children or a special Havana-cigar instinct in old bachelors.

That the behavior of *sanguinea* towards Lomechusa proves nothing in regard to intelligence, even when the word is used, as it is always used by Wasmann, in the scholastic sense, that is, as equivalent to reason, or ratiocination, has been shown by Hobhouse. After referring to Wasmann's conclusions, he says: "Difficult as it is to conceive the psychological conditions under which such contrasts are possible, we may still get some help from the analogy of human action. When comparative psychologists take occasional inconsistency as proving the utter absence of intelligence (in animals) they are using an argument which would equally disprove the existence of intelligence in man. After all, is an ant nourishing parasites that destroy its young guilty of a greater absurdity than, say, a mother promoting her daughter's happiness by selling her to a rich husband, or an inquisitor burning a heretic in the name of Christian charity, or an Emperor forbidding his troops to give quarter in the name of civilization? The mother really desires her daughter's happiness, but her conception of the means thereto is confused, and rendered self-contradictory by worldly ambitions. The inquisitor's conception of Christian charity is similarly corrupted by the subtle corporate egoism of a Church and the cruel pedantry of bad theology. Even the Emperor has some conception of civilization, but it is the civilization of militarism. In all cases there impinge on the avowed plan of action conflicting impulses of a kind not to stop the course of action, but to merge in it and distort it."

Hobhouse also comments trenchantly on Wasmann's conception of the maneuvers of the Divine Wisdom in maintaining the equilibrium of parasite and host, but I will pass over this matter, because it involves a consideration of the problem of evil and belongs to the philosopher and the theologian. The cases of social parasitism considered in the first part of this lecture and the behavior of *sanguinea* and Lomechusa suggest a few concluding remarks on a matter that is often overlooked. It is evident that a parasitic species is more seriously affected and at a much greater disadvantage than a host species, notwithstanding the suffering or death that may be inflicted on individual host colonies. Without exception, the hosts of all the known social parasites and Lomechusini are very common, prolific, widely distributed and therefore

very plastic or adaptable ant, and the instances of infection of these hosts are local or sporadic. This is even the case with *Formica fusca*, which occurs practically over the whole northern hemisphere and is infested by an extraordinary series of social parasites. It is enslaved by *F. sanguinea* and *Polyergus rufescens* and serves as the temporary host of many parasitic Formicas, including *rufa, truncicola, dakotensis, exsecta, exsectoides*, etc. We may conclude, therefore, that *fusca* and the other hosts of parasitic ants and Lomechusini have developed more or less resistance or even a certain local immunity to the inroads of the parasites, and that the parasites even when successful exploit merely that margin of super-abundant vitality and fecundity which every healthy organic species possesses. Hence the occasional destruction of colonies by the parasites does not seriously endanger the life of the host species. If this were the case the hosts would be scarce or would have disappeared long ago. The same considerations probably apply to the human species, for it would seem that only man's world-wide distribution, great fecundity and wonderful adaptability have enabled him to survive all the terrible exploitations to which he has been subjected.

THE THEORY OF RELATIVITY AND ITS INFLUENCE ON SCIENTIFIC THOUGHT[1]

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IN the days before Copernicus the earth was, so it seemed, an immovable foundation on which the whole structure of the heavens was reared. Man, favorably situated at the hub of the universe, might well expect that to him the scheme of nature would unfold itself in its simplest aspect. But the behavior of the heavenly bodies was not at all simple; and the planets literally looped the loop in fantastic curves called epicycles. The cosmogonist had to fill the skies with spheres revolving upon spheres to bear the planets in their appointed orbits; and wheels were added to wheels until the music of the spheres seemed well-nigh drowned in a discord of whirling machinery. Then came one of the great revolutions of scientific thought, which swept aside the Ptolemaic system of spheres and epicycles, and revealed the simple plan of the solar system which has endured to this day.

The revolution consisted in changing the viewpoint from which the phenomena were regarded. As presented to the earth the track of a planet is an elaborate epicycle; but Copernicus bade us transfer ourselves to the sun and look again. Instead of a path with loops and nodes, the orbit is now seen to be one of the most elementary curves—an ellipse. We have to realize that the little planet on which we stand is of no great account in the general scheme of nature; to unravel that scheme we must first disembarrass nature of the distortions arising from the local point of view from which we observe it. The sun, not the earth, is the real center of the scheme of things—at least of those things in which astronomers at that time had interested themselves—and by transferring our viewpoint to the sun the simplicity of the planetary system becomes apparent. The need for a cumbrous machinery of spheres and wheels has disappeared.

Every one now admits that the Ptolemaic system, which regarded the earth as the center of all things, belongs to the dark

[1] The Romanes Lecture for 1922, delivered in the Sheldonian Theatre, Oxford, and printed by the Clarendon Press.

ages. But to our dismay we have discovered that the same *geocentric* outlook still permeates modern physics through and through, unsuspected until recently. It has been left to Einstein to carry forward the revolution begun by Copernicus—to free our conception of nature from the terrestrial bias imported into it by the limitations of our earthbound experience. To achieve a more neutral point of view we have to imagine a visit to some other heavenly body. That is a theme which has attracted the popular novelist, and we often smile at his mistakes when sooner or later he forgets where he is supposed to be and endows his voyagers with some purely terrestrial appanage impossible on the star they are visiting. But scientific men, who have not the novelist's license, have made the same blunder. When, following Copernicus, they station themselves on the sun, they do not realize that they must leave behind a certain purely terrestrial appanage, namely, *the frame of space and time* in which men on this earth are accustomed to locate the events that happen. It is true that the observer on the sun will still locate his experiences in a frame of space and time, if he uses the same faculties of perception and the same methods of scientific measurement as on the earth; but the solar frame of space and time is not precisely the same as the terrestrial frame, as we shall presently see.

I think you will readily understand what is meant by a *frame* of space and time. It is the system of location to which we appeal when we state, for example, that one event is 100 miles distant from and 10 hours later than another. The terms space and time have not only a vague descriptive reference to a boundless void and an ever-rolling stream, but denote an exact quantitative system of reckoning distances and time-intervals. Einstein's first great discovery was that there are many such systems of reckoning—many possible frames of space and time—exactly on all fours with one another. No one of these can be distinguished as more fundamental than the rest; no one frame rather than another can be identified as the scaffolding used in the construction of the world. And yet one of them does present itself to us as being the actual space and time of our experience; and we recoil from the other equivalent frames which seem to us artificial systems in which distance and duration are mixed up in an extraordinary way. What is the cause of this invidious selection? It is not determined by anything distinctive in the frame; it is determined by something distinctive in us—by the fact that our existence is bound to a particular planet and our motion is the motion of that planet. *Nature* offers an infinite choice of frames; *we* select the one in which we and our petty terrestrial concerns take the most distinguished position. Our mis-

chievous, geocentric outlook has cropped out again unsuspected, persuading us to insist on this terrestrial space-time frame which in the general scheme of nature is in no way superior to other frames.

The more closely we examine the processes by which events are assigned to their positions in space and time, the more clearly do we see that our local circumstances play a considerable part in it. We have no more right to expect that the space-time frame on the sun will be identical with our frame on the earth than to expect that the force of gravity will be the same there as here. If there were no experimental evidence in support of Einstein's theory, it would nevertheless have made a notable advance by exposing a fallacy underlying the older mode of thought—the fallacy of attributing unquestioningly a more than local significance to our terrestrial reckoning of space and time. But there is abundant experimental evidence for detecting and determining the difference between the frames of differently circumstanced observers. Much of the evidence is too technical to be discussed here, and I can only refer to the Michelson-Morley experiment. I fear that some of you must be getting rather tired of the Michelson-Morley experiment; but those who go to a performance of Hamlet have to put up with the Prince of Denmark.

This famous experiment is a simple test whether light travels at the same speed in two different directions. For this purpose an apparatus is constructed with two equal arms at right angles, providing two equal tracks for the light. A beam of light is divided into two parts so that one part travels along one arm and back, and the other along the other arm and back. The two rays then reunite, and by delicate interference tests it is possible to tell if one has been delayed more than the other; a delay of less than a thousand-billionth of a second could be detected. The experiment is simply a race between two light-rays with equal tracks, but pointing in different directions; the result turns out to be a dead-heat. At first sight this is just what would be expected; and one almost wonders why it should have been thought worth while to try the experiment. But Michelson, like a good Copernican, had stationed himself on the sun to watch the race; accordingly he realized that the apparatus was being borne along by the earth's orbital motion with a speed of 20 miles a second. Consequently the light does not travel exactly the double length of the arm; starting at one end it has to go to the turning-mark at the other end which has moved on a little in the meantime; then it returns to the place which the starting-mark has travelled to whilst the race is in progress. That does not add up to exactly the double length of the

arm. Making the calculations we easily find that, although the two arms are equal, the two light-journeys are unequal; the competitor whose track lies in the line of the earth's motion has the longer journey, and is at a disadvantage. And yet according to the experiment he does not suffer the expected delay. From our standpoint on the sun, the experiment seems to have gone wrong; Copernicus has met with a rebuff, and Ptolemy is triumphant.

But that is because we have not admitted the full consequences of transferring our standpoint to the sun. We have all the while been keeping one foot on earth. Of course, the whole experiment turns on the two arms having been first adjusted to perfect equality. This could only be ascertained by experiment; and the test applied was to rotate the apparatus through a right angle, so that if, for example, the journey in the line of the earth's motion had had the advantage of the shorter arm on one occasion, the transverse journey would have had it on the repetition. That is a perfectly satisfactory test for a terrestrial observer; to turn a rod from one direction to another is the simple and direct way of marking out equal lengths. But the test is not satisfactory to an observer on the sun; he would not think of attempting to partition equal lengths of space by means of rods travelling at 20 miles a second. His frame of space—the space not only of refined measurement, but also of the cruder measurements made with the sense-organs of his body which determine his perception of space—is partitioned by appliances at rest relatively to him, *e. g.*, his own eyes and limbs. Lengths of objects carried on the earth must be judged by him according to the room they occupy in his own frame. In the space of the terrestrial observer the two arms of the apparatus were adjusted to equal length; but in the re-partitioned space of the solar observer they may quite well occupy unequal lengths, and when we take the viewpoint of an observer on the sun we must not overlook this inequality. This inequality is not so much a hypothesis proposed to account for Michelson's result as a direct deduction from it. The two light-journeys were found to occupy equal times; this clearly shows that the arm in the less favored direction is shorter than the other so as to counterbalance the handicap to which I have referred.[2]

When the apparatus is turned through a right angle, the experiment still gives the same result. It does not matter which of

[2] The only alternative is that (relatively to a solar observer) the velocity of light differs in different directions, at least in the region where the experiment is conducted. This would presumably be due to some influence of the moving earth on the propagation of light (convection of the ether). This explanation was at one time favored, but it could not be reconciled with the observed phenomena of the aberration of light.

the two arms we place in the line of the earth's motion; that arm must be shorter than the other. In other words each arm must automatically contract when it is turned from the transverse to the longitudinal position with respect to its line of motion. This is the famous FitzGerald contraction of a moving rod. It is of the same amount whatever the material of the rod, and depends only on the speed of its motion. For the earth's orbital motion the contraction amounts to one part in 200 million; in fact the earth's diameter in the direction of its motion is always shortened by 2½ inches, the transverse diameter being unaffected.

This contraction of a moving material object was first revealed to us by the Michelson-Morley experiment; but it is not at all disagreeable to theoretical anticipations. We have to remember that a rod consists of a large number of molecules kept in position by their mutual forces. The chief force is the force of cohesion, and there is little doubt that this is of electrical nature. But when the rod is set in motion, the electrical forces inside it must change. For example, each electric charge when put in motion becomes *an electric current;* and the currents will exert magnetic attractions on each other which did not occur in the system at rest. Under the new system of forces the molecules will have to find new positions of equilibrium; they become differently spaced; and it is therefore not surprising that the form of the rod changes. Without going beyond the classical laws of Maxwell we can anticipate theoretically what will be the new equilibrium state of the rod, and it turns out to be contracted to the exact amount required by the Michelson-Morley result.

The contraction of the moving rod ought not to surprise us; it would be much more surprising if the rod were to maintain the same form in spite of the alteration of the electrical forces which determine the spacing of the molecules. But the remarkable thing is that the contraction is only apparent according to the outlook of the solar observer; and we on the earth, who travel with the rod, can not appreciate it. The fact that the contraction happens to be very small is irrelevant. For convenience suppose that the earth's velocity is 8,000 times faster, so that the contraction amounts to something like a half the original length. We should still fail to notice it in everyday life. Let us say that the direction of the earth's motion is vertically upwards. I turn my arm from horizontal to vertical and it contracts to half its length. No, you can not convince me I am wrong; I am not afraid of a yard-measure. Bring one and measure my arm; first horizontally, the result is 30 inches; now vertically, the result is 30—half-inches! Because you must remember that you have turned the scale into

the line of the earth's motion so that each inch-division contracts to half an inch. "But we can see that your arm does not contract. Are we not to trust our eyes?" Certainly *not*, unless you first correct your visual impressions for the contraction of the retina in the vertical direction, and for the effect of our rapid motion on the apparent direction of propagation of the waves of light. You will find, when you calculate these corrections, that they just conceal the contraction. "But if the contraction takes place, ought one not to feel it happening to the arm?" Not necessarily; I am an observer of the earth, and my feelings like other sense-impressions belong to the geocentric outlook on nature, which Copernicus has persuaded us to abandon.

Take a pair of compasses and twiddle them on a sheet of paper. Is the resulting curve a circle or an ellipse? Copernicus from his standpoint on the sun declares that owing to the FitzGerald contraction the two points drew nearer together when turned in the direction of the earth's orbital motion; hence the curve is flattened into an ellipse. But here I think Ptolemy has a right to be heard; he points out that from the beginning of geometry circles have always been drawn with compasses in this way, and that when the word "'circle" is mentioned every intelligent person understands that this is the curve meant. The same pencil line is in fact a circle in the space of the terrestrial observer and an ellipse in the space of a solar observer. It is at the same time a moving ellipse and a stationary circle. I think that illustrates as well as possible what we mean by *the relativity of space*.

It is sometimes complained that Einstein's conclusion that the frame of space and time is different for observers with different motions tends to make a mystery of a phenomenon which is not after all intrinsically strange. We have seen that it depends on a contraction of moving objects which turns out to be quite in accordance with Maxwell's classical theory. But even if we have succeeded in explaining it to ourselves intelligibly, that does not make the statement any the less true! A new result may often be expressed in various ways; one mode of statement may sound less mysterious; but another mode may show more clearly what will be the consequences in amending and extending our knowledge. It is for the latter reason that we emphasize the relativity of space—that lengths and distances differ according to the observer implied. Distance and duration are the most fundamental terms in physics; velocity, acceleration, force, energy, and so on, all depend on them; and we can scarcely make any statement in physics without direct or indirect reference to them. Surely then we can best indicate the revolutionary consequences of what we have learned by the

statement that distance and duration, and all the physical quantities derived from them, do not as hitherto supposed refer to anything absolute in the external world, but are relative quantities which alter when we pass from one observer to another with different motion. The consequence in physics of the discovery that a yard is not an absolute chunk of space, and that what is a yard for one observer may be eighteen inches for another observer, may be compared with the consequences in economics of the discovery that a pound sterling is not an absolute quantity of wealth, and in certain circumstances may "really" be seven and sixpence. The theorist may complain that this last statement tends to make a mystery of phenomena of currency which have really an intelligible explanation; but it is a statement which commends itself to the man who has an eye to the practical applications of currency.

Ptolemy on the earth and Copernicus on the sun are both contemplating the same external universe. But their experiences are different, and it is in the process of experiencing events that they become fitted into the frame of space and time—the frame being different according to the local circumstances of the observer who is experiencing them. That, I take it, is Kant's doctrine, "Space and time are forms of experience." The frame then is not in the world; it is supplied by the observer and depends on him. And those relations of simplicity, which we seek when we try to obtain a comprehension of how the universe functions, must lie in the events themselves before they have been arbitrarily fitted into the frame. The most we can hope for from any frame is that it will not have distorted the simplicity which was originally present; while an ill-chosen frame may play havoc with the natural simplicity of things. We have seen that the simplicity of planetary motions was obscured in Ptolemy's frame, and became apparent in Copernicus's frame. But for ordinary terrestrial phenomena the position is reversed and Ptolemy's frame allows their natural simplicity to become apparent. In Copernicus's frame the most simple phenomena are brought about by highly complicated processes which mutually cancel one another. Ordinary objects contract and expand as they are moved about, and the changes are concealed by an elaborate conspiracy in which all the quantities of nature—electrical, optical, mechanical, gravitational—have joined. In Copernicus's frame we have a great complication of description which has no counterpart in anything occurring in the external world; because the terms of our description refer to the irrelevant process of fitting into the selected frame of space and time. This elaborate Copernican scheme rather reminds one of the schemes of the White Knight—

But I was thinking of a plan
To dye one's whiskers green,
And always use so large a fan
That they could not be seen.

We do not deny the subtlety and the remarkable efficiency of the plan; but we may be allowed to question whether it is the simplest interpretation of the drab monotony of the face of nature presented to us. The simple fact is that a terrestrial or Ptolemaic frame fits naturally the terrestrial phenomena, and a solar or Copernican frame fits the phenomena of the solar system; but we can not make one frame serve for both without introducing irrelevant complications.

We go beyond Copernicus nowadays, and are not content with a visit to the sun. Why choose the sun rather than some other star in order to obtain an undistorted view of things? The astronomer now places himself so as to travel with the center of gravity of the stellar universe, and is not even then quite satisfied. The physicist dreams of a land of Weissnichtwo, which shall be truly at rest in the ether. We realize the distortion imported into the world of nature by the parochial standpoint from which we observe it, and we try to place ourselves so as to eliminate this distortion—so as to observe that which actually *is*. But it is a vain pursuit. Wherever we pitch our camera, the photograph is necessarily a two-dimensional picture distorted according to the laws of perspective; it is never a true semblance of the building itself.

We must try another plan. I do not think we can ever eliminate altogether the human element in our conception of nature; but we can eliminate a particular human element, namely, this framework of space and time. If our thought must be anthropocentric, it need not be geocentric. Nor are we permanently better off if we merely substitute the space-time frame of some other star or standard of motion. We must leave the frame entirely indeterminate. When we do that, we find that the world common to all observers—in which each observer traces a different space-time frame according to his own outlook—is a world of four dimensions. When we look at any object, say a chair, the impression on our eyes is a two-dimensional picture depending on the position from which we are looking; but we have no difficulty in conceiving of the chair as a solid object, not to be identified with any one of our two-dimensional pictures of it, but giving rise to them all as the position of the observer is varied. We must now realize that this solid chair in three dimensions is itself only an appearance, which changes according to the motion of the observer, and that there is a super-object in four dimensions, not to be identified with the

three-dimensional chair in Ptolemy's scheme, or the same chair in Copernicus's scheme, but giving rise to both these appearances. The synthesis of a three-dimensional chair from a number of flat pictures is easy to us because we are accustomed to assume different positions in rapid succession; indeed our two eyes give us slightly different points of view simultaneously. By sheer necessity our brains have been forced to construct the conception of the solid chair to combine these changing appearances. But we do not vary our motion to any appreciable extent and our brains have not hitherto been called upon to combine the appearances for different motions; thus the effort which we now ask the brain to make is a novel one. That explains why the result seems to transcend our ordinary mode of thought.

The discovery, or one should rather say the rediscovery, of the world of four dimensions is due to Minkowski. Einstein had worked out fully the relations between the frames of space and time for observers with different motions. To the genius of Minkowski we owe the realization that these frames are merely systems of partitions arbitrarily drawn across a four-dimensional world which is common to all observers.

There is a strange delusion that the fourth dimension must be something wholly beyond the conception of the ordinary man, and that only the mathematician can be initiated into its mysteries. It is true that the mathematician has the advantage of understanding the technical machinery for solving the problems which may arise in studying the world of four dimensions; but as regards the conception of the four dimensions of the world his point of view is the same as that of anybody else. Is it supposed that by intense thought he throws himself into some state of trance in which he perceives some hitherto unsuspected direction stretching away at right angles to length, breadth and thickness? That would not be much use. The world of four dimensions, of which we are now speaking, is perfectly familiar to everybody. It is obvious to every one—even to the mathematician—that the world of solid and permanent *objects* has three dimensions and no more; that objects are arranged in a threefold order, which for any particular individual may be analyzed into right-and-left, backwards-and-forwards, up-and-down. But it is no less obvious to every one that the world of *events* is of four dimensions; that events are arranged in a fourfold order, which in the experience of any particular individual will be analyzed into right-and-left, backwards-and-forwards, up-and-down, *sooner-and-later*. The subject of our study is external nature, which is a world of events, common to all observers, but represented by them differently in their parochial frames of space

and time; it is obvious to the most commonplace experience that this absolute world contains a fourfold order.[3]

The news that the events around us form a world of four dimensions is as stale as the news that Queen Anne is dead. The reason why the relativist resurrects this ancient truism is because it is only in this undissected combination of four dimensions that the experiences of all observers meet. In our own experience one dimension is sharply separated from the other three and is distinguished as time; but our experience is solely terrestrial, and if we insist on building the scheme of nature on purely terrestrial experience we are limiting ourselves to the medieval geocentric system of the world.

We have been accustomed to regard the enduring world as composed of a continuous succession of instantaneous states, as though the world of events were *stratified*. Each event is supposed to lie in a definite instant or stratum, and the orderly succession of these strata makes up the whole of reality. The instant "now" represents one such stratum running throughout the universe. Indeed, we are accustomed to extend it beyond the universe, and we even use the word "now" with reference to the existence of those who have passed away from the material world. The investigations of the relativity theory show incontrovertibly that this supposed stratification is an illusion; there is not the slightest evidence for such a view of world structure. The instantaneous state, which we have hitherto taken to be a natural stratum in the four-dimensional world of events is merely an arbitrary partition created by ourselves to correspond with our geocentric outlook. We can take a differently inclined partition,[4] that is to say, a section which includes on the one side of us events which happened a little while

[3] The relativity theory does not suggest that there is such a thing in nature as a four-dimensional *space*. The whole object of the recognition of the four-dimensional world is to eliminate the harassing frame of space.

[4] The inclination must not exceed a certain limit. This limiting angle may be regarded as a fundamental constant of the world-structure, and owing to its fundamental character it appears in many kinds of phenomena; for example, it determines the velocity of propagation of light. The instant on the sun which is simultaneous with a given instant on the earth is indeterminate (varying according to the space and time frame employed) but only within a range of 16 minutes. Any event on the sun happening before this 16 minutes is *absolutely* in the past, all observers agreeing on this point; in fact it would be possible for us to have already received a wireless message announcing its occurrence. Events after the 16 minutes are in the *absolute* future. The neutral zone which is (absolutely) neither past nor future becomes proportionately wider as the distance increases; at the nearest fixed star it extends to 8 years, and at the most distant stars yet known it reaches 400,000 years.

ago and on the other side of us events which have not yet happened; such a farcical combination is in every way equivalent to our so-called instantaneous state, and indeed it *is* an instantaneous state according to the outlook of some non-terrestrial observer with suitably assigned motion.

It is so contrary to our natural prejudices to recognize that the world-wide instant *now* is created by ourselves and has no existence apart from our geocentric outlook, that I will spend a few moments trying to show its artificiality. When I say that I am conscious of an instant *now*, I am only conscious of it in so far as it is *here*—inside me. What then has led me to imagine that there exists a continuation of it outside me? It is because I look out on the world and see various events happening "now," so that I jump to the conclusion that this instant of which I am conscious has to be extended to include them. But that idea is another inheritance from the dark ages, overthrown by Römer in 1675. It is not the events themselves but the sense-impressions to which they give rise which are happening in the instant *now*. So my justification for placing the events outside me in the instants of which I am conscious has entirely disappeared. Unfortunately, however, the crude outlook was not abolished, but patched up; it was found that the immediate difficulties could be met by locating the external events not in the instant of our visual perception of them but in an instant which we had experienced a little time back—allowing, as we say, for the time of propagation of light. Thus our instants were still made to extend through space; but they were carried like partitions among the events by an artificial process of computation, and no longer by immediate intuition. The relativity theory recognizes these *world-wide instants* for what they are—artificial partitions constructed for purposes of calculation. I may add that it in no way tampers with the *local instants* which form the stream of our consciousness; it fully recognizes that the chain of events in such a time-succession is a series of an entirely distinctive character from the succession of points along a line in space. Those who suspect that Einstein's theory is playing unjustifiable tricks with time should realize that it leaves entirely untouched that time-succession of which we have intuitive knowledge, and confines itself to overhauling the artificial scheme of time which Römer first introduced into physics.

The study of the four-dimensional world of events gives us a new insight into the processes of nature because it removes the irrelevant stratification in a particular direction—the instantaneous states—which we have so unnecessarily introduced in our customary outlook. When this stratification is ignored we are en-

abled to see the processes in their simplest aspect, though not, of course, in their most familiar aspect. We must distinguish between simplicity and familiarity; a pig may be most familiar to us in the form of rashers, but the *unstratified* pig is a simpler object of study to the biologist who wishes to understand how the animal functions.

I will conclude this part of the argument with an experimental application which illustrates the power of Einstein's method. Much study has of late been given to electrons moving with very high speeds; for example, the β particles shot off from radioactive substances are negative electrons which sometimes attain speeds of 100,000 miles a second. It is found by experiment that the rapid motion produces an increase of mass of these particles. I want to show that the theory of relativity gives a very simple explanation of just how this increase of mass occurs. But I must first remark that an explanation had been previously given which had generally been accepted as satisfactory. The phenomenon was actually predicted by J. J. Thomson before relativity was thought of; because, assuming that the mass of a β particle is of electrical origin, an application of Maxwell's equations shows that it ought to increase with velocity. But the precise law of increase can not be predicted on this basis, since various plausible assumptions lead to slightly different results. Moreover, Maxwell's equations are after all only empirical laws, with a mystery of their own; it was a notable advance to connect the change of mass at high speeds with other phenomena whose strangeness has disappeared by long familiarity, but there is still scope for a more far-reaching explanation. Einstein takes us straight to the root of the mystery, and he clears up one point which was misleading, if not actually wrong, in the older explanation. The change of mass does not in any way depend on whether the mass is of electrical origin or not; it arises simply from the fact that mass is a *relative* quantity, depending by its definition on the relative quantities length and time. Let us look at the β particle from its own point of view; it is just an ordinary electron in no way different from any other. "But it is travelling unusually rapidly!" "That," says the electron, "is a matter of opinion. So far as I am aware I am at rest, if the word 'rest' has any meaning. In fact I was just contemplating with amazement *your* extraordinary speed of 100,000 miles a second with which you are shooting past me." Of course our motion is of no particular concern to the electron, and it will not modify its constitution on our account; so it keeps its mass, radius, electric field, etc., equal to the standard constants applying to electrons in general. These terms are relative, and refer therefore to some particular frame

of space and time—clearly the frame appropriate to an electron in self-contemplation, *viz.*, the one with respect to which it is at rest. But this frame is not the usual geocentric frame to which *we* refer quantities such as length, time, and mass; there is a difference of 100,000 miles a second between our station of observation and that of the β particle in self-contemplation. It is a mere matter of geometry to discover what the β particles' lengths and times become when referred to the partitions which we have drawn across the world. But when we calculate the consequential change of mass resulting from the changes of length and time, we find that it should be increased in precisely the proportion indicated by the most refined experiments.

The point is that every electron, at rest or in motion, is a perfectly constant structure; but we distort it by fitting it into the space-time frame appropriate to our own motion with which the electron has no concern. The greater our motion with respect to the electron, the greater will be the distortion. The distortion is not produced by any physical agency at work in the electron; it is a purely subjective distortion depending on our transformation of the reference frame of space and time. This distortion involves a change in our physical description of the electron in terms of mass, shape, size; and in particular the change of mass agrees precisely with that found experimentally.

You see that it is not altogether idle discussing the natural space-time frames for observers moving with huge velocities. We know of no animate observers with these speeds; but we do know of inanimate material objects. Their common resemblance is obscured when we refer them indiscriminately to our irrelevant geocentric frame; we think they have altered their properties, varied in mass, and so on; but the resemblance is restored when we refer each individual to the frame appropriate to it, and so describe them all in comparable terms.

Our measurements of distance in space are found to be subject to certain laws—the laws of geometry. But it has now become impossible to regard the subject of space-geometry as complete in itself. Consider a triangle formed by three points (or events) in the four-dimensional world; if we happen to have drawn our instantaneous strata so that the three points lie in one stratum, then the triangle is a space-triangle and its properties fall within the scope of our classical geometry. But another observer will draw his strata in a different direction, and for him the triangle would be partly in space and partly in time, so that it would not be a fit subject for space-geometry. The subject of geometry is in a desperate condition, because Copernicus and Ptolemy not merely dis-

agree as to the geometry of a configuration; they even disagree as to whether a given configuration is one to which space-geometry is applicable. It is clear that to save it we must extend our geometry so as to include time as well as space. Let me give an illustration of this extension. The terrestrial observer can have a space-triangle (formed by three points or events at the same instant) whose sides he can measure with scales; he can also have a "time-triangle," formed by three events on different dates, whose sides he must measure with *clocks*.[5] You all know the law of the space-triangle—that if you measure with a scale from A to B and from B to C the sum of the readings is always *greater* than the measure from A to C. It is not so well known that there is a precisely analogous law for the time-triangle—that if you measure with a clock from A to B and from B to C the sum of the readings is always *less* than the reading of a clock measuring directly from A to C. In the space-triangle any two sides are together *greater* than the third side; in the time-triangle two sides are together *less* than the third side.[6] Both these laws must be combined in our general geometry of four dimensions, so that it will not be quite so simple a geometry as that to which we are accustomed.[7]

But the point to which I would especially direct attention is this. Evidently the proposition which I have given you about time-triangles can not be dissociated from the corresponding proposition about space-triangles. When we give up the medieval geocentric standpoint, we must recognize that they belong to one geometry, of which our ordinary space-geometry is only a part or projection. But if you examine the proposition about time-triangles, you will see that it is a statement about the behavior of clocks when they move about, a subject which obviously comes under the heading of mechanics. When we deal with the four-dimensional world we can no longer distinguish between geometry and mechanics. They become the same subject. When we have completely mastered the geometry of the world of events, we shall have inevitably learned

[5] The three events must not be at the same place since that would give a time-*line* not a triangle. The clock must move so that the two events whose time-distance is to be determined both happen where it is, just as the scale must be directed so that the two points fall on it. You are not allowed to "bend" the clock, *i. e.*, apply force so as to make it move with other than uniform velocity, any more than you are allowed to bend the scale by applying force.

[6] Of course, it is not true that *any* two sides are less than the third side. A clock, unlike a scale, can only measure in one direction, *viz.*, from past to future, so that the sides $AB + BC$ and AC can be chosen in only one way.

[7] This involves only a comparatively trifling generalization of Euclidean geometry, not to be confused with the "non-Euclidean" geometry introduced later in the lecture.

the mechanics of it. That is why Einstein, studying the geometry of the world and discovering that it was strictly non-Euclidean, found that he was at the same time studying the mechanical force of gravitation. And when he had made up his mind which of the possible varieties of non-Euclidean geometry was obeyed, and so settled the laws of the new geometry, the same decision settled the law of gravitation—a law approximating to, but not identical with, the law which Newton had given.

Here a wide vista opens before us. We see that two great divisions of mathematical physics, *viz.*, geometry and mechanics, have met in the four-dimensional world. It is not merely that mechanical problems can be treated by formulæ originally belonging to pure geometry; that device has long been in use. Experimental geometry and mechanics actually relate to the same subject-matter: and the young student who discovers experimental laws with ruler and compasses and cardboard figures, and later goes on to pendulums and spring-balances, is developing a single subject which can not be divided any more than the subject of magnetism can be divided from electricity.

It is through this unification of geometry and mechanics that I should like to approach the problem of gravitation, showing that a field of force is a manifestation of the geometry of space and time. But I fear that that would be too technical; so we will approach it from a different angle.

We have shown that the contemplation of the world from the standpoint of a single observer is liable to distort its simplicity, and we have tried to obtain a juster idea by taking into account and combining other points of view. The more standpoints the better. Let us now consider another point of view, which we have not previously thought about—the point of view of an observer who has tumbled out of an aeroplane and is falling headlong. In many respects his is an ideal situation—temporarily. Unfortunately on *terra firma* we are continually subjected to a very disturbing influence; we undergo a terrific bombardment by the molecules of the ground, which are hammering on the soles of our boots with a total force of some ten stone weight pressing us upwards. Now our bodies are the scientific appliances which we use to make our common observations of the world. I am sure that no physicist would permit any one to enter his laboratory and hammer on his clocks and galvanometers while he was observing with them; at any rate he would think it necessary to apply some corrections for the effect of the disturbance. Let us then allow ourselves to fall freely *in vacuo;* then we shall be free from this disturbing bombardment and able to take a much more natural view of what is going on around us.

While falling, we perform the experiment of letting go an apple held in the hand. The apple is now free, but it can not fall any more than it was falling already; consequently it remains poised in contact with our hand. In our new outlook—in our new frame of space and time—an apple does not drop. There is no mysterious force accelerating it. And remember that this new frame of space and time is the natural frame of a free observer; whereas the old frame, in which the mysterious accelerating force occurred, was the frame of a very much disturbed observer. It is true that when we look down at the earth we see trees and houses rushing up to meet us; but there is no mystery about that. There is an obvious cause for it; plainly they are being propelled upwards from below by that molecular bombardment which I have mentioned. You see that the apple's view of things is simpler than Newton's. Newton had to invent a mysterious force dragging the apple down; the apple observes only a familiar physical agency propelling Newton up.

It is not my purpose to emphasize unduly the superiority of the apple's view over Newton's, but rather to regard both on an equal footing. I have perhaps been a little unfair to Newton. His position on the surface of the earth was unfortunate, but he would have been perfectly content to be at the center of the earth, where he could have remained without support, *i. e.*, without disturbance by molecular bombardment. From there he would still have observed the well-known acceleration of the apple; and the apple would have observed a corresponding acceleration of Newton without any molecular bombardment causing it. From either point of view there is a mysterious agent at work. How shall we picture to ourselves this agent? Shall we picture it as a force—a tug of some kind? But if so, to which of them is the tug applied? If we take the standpoint of Newton the tug is applied to the apple, if the standpoint of the apple the tug is applied to Newton; so that in our synthesis of all standpoints we can not decide which is being tugged, and the picture of gravitation as a tugging agent becomes impossible. Einstein replaces it by a different picture, which we shall perhaps better understand if we compare it with a very similar revolution of scientific thought which occurred long ago.

The ancients believed that the earth was flat. The small portion of its surface with which they were chiefly concerned could be represented without serious distortion on a flat map. As more distant countries were added, it would be natural to think that they also could be included in the flat map. You have all seen such maps of the world, *e. g.*, Mercator's projection, and you will remember how Greenland appears enormously exaggerated in size.

Now those who adhered to the flat-earth theory must hold that the flat map gives the *true* size of Greenland. How then would they explain that travellers in that country reported that the distances were much shorter? They would, I suppose, invent a theory that a demon resided in that country who helped travellers on their way, making the journeys appear much shorter than they "really" were. No doubt the scientists would preserve their self-respect by using some Græco-Latin polysyllable instead of the word "demon," but that must not disguise from us the fact that they were appealing to a *deus ex machina*. The name demon is rather suitable, however, because he has the impish characteristic that we can not pin him down to any particular locality. We might equally well start our flat map with its center in Greenland; then it would be found that journeys there were quite normal, and that the activities of the demon were disturbing travellers in Europe. We now recognize that the true explanation is that the earth's surface is curved; and the demoniacal complications appeared because we were forcing the earth's surface into an inappropriate flat frame which distorts the simplicity of things.

What has happened in the case of the earth has happened also in the case of the world, and a similar revolution of thought is needed. An observer, say at the center of the earth, finds that there is a frame of space and time—a flat or Euclidean frame—in which he can locate things happening in his neighborhood without distorting their natural simplicity. There is no gravitation, no tendency of bodies to fall, so long as the observer confines his observations to his immediate neighborhood. He extends this frame of space and time to greater distances, and ultimately to the earth's surface where he encounters the phenomenon of falling apples. This new phenomenon must be accounted for, so he invents a *deus ex machina* which he calls gravitation to whose activities the disturbance is attributed. But we have seen that we may just as well start with the falling apple. It has a flat frame of space and time into which phenomena in its neighborhood fit without distortion; and from its point of view bodies near it do not undergo any acceleration. But when it extends this frame farther afield, the simplicity is lost; and it too has to postulate the demon force of gravitation existing in distant parts, and for example causing undisturbed objects at the center of the earth to fall towards it. As we change from one observer to another—from one flat space-time frame to another—so we have to change the region of activity of this demon. Is not the solution now apparent? The demon is simply the complication which arises when we force the world into a flat Euclidean space-time frame into which it does not fit without

distortion. It does not fit the frame, because *it is not a Euclidean or flat world*. Admit a curvature of the world and the mysterious disturbance disappears. Einstein has exorcised the demon.

Einstein, recognizing that in the phenomena of gravitation he was not dealing with a "tug" but with a curvature of the world, had to reconsider the law of gravitation. He could not make any possible law of curvature correspond exactly with the previously assumed law of tugging. Thus he was led to propound a new law of gravitation—a law which in most practical cases differs very little from that of Newton, although it has an essentially different foundation. I need not here dwell on the very remarkable way in which Einstein's emendation of the law of gravitation has been confirmed both by the anomalous secular change in the orbit of the planet Mercury, and by the observed displacement of the stars near the sun during the total eclipse of 1919. I might, however, remind you that in the latter observation the point at issue between Newton's and Einstein's theory was not the *existence* of a deflexion of light-rays passing near the sun but the amount of the deflexion, Einstein predicting twice the deflexion possible on the Newtonian theory. The larger deflexion was quantitatively confirmed by the eclipse observations. Einstein's main achievement is a new law, not a new explanation, of gravitation. He attributes the gravitation of massive bodies to a curvature of the world in the region surrounding them and so throws a flood of light on the whole problem; but he is not primarily concerned to explain how material bodies produce (or are associated with) this curvature of the world around them, nor how this curvature is made subject to a law. Although it would be an entire misunderstanding of Einstein's attitude in propounding the general relativity theory to regard it as a search for an explanation of gravitation, nevertheless I think that the further following up of his ideas has led to a genuine explanation as complete as could be desired. But I am not going to give you the explanation in this lecture; sometimes an explanation requires a great deal of explaining.[8]

[8] The following brief outline will give a hint of the nature of the explanation. Einstein's law of gravitation is usually expressed as a set of ten very lengthy differential equations; these equations are exactly equivalent to the geometrical statement that "the radius of spherical curvature of any 3-dimensional section of the 4-dimensional world is a universal constant length, the same for all points of the world and for all directions of the section." The law therefore implies that the world has a certain type of homogeneity and isotropy (not, however, the *complete* homogeneity and isotropy of a sphere). To explain the law of gravitation and the phenomena governed by it, we have to explain how this isotropy and homogeneity is secured. Our explanation is that the homogeneity and isotropy is not initially in the external world, but *in the measurements which we make of it*. It is introduced in all

I think that we can without mathematics form a general idea of why Einstein found it necessary to amend Newton's law of gravitation. Let us return to the illustration of the pig, and imagine that we wish to discover the law governing the distribution of fat and lean in the animal. From the breakfast-table standpoint a plausible type of law would be that half of each rasher is fat and the other half lean; and if this turned out to be confirmed very approximately by observation we might well imagine that we had discovered the exact law of porcine structure. But the case is altered if we give up the breakfast-table standpoint and contemplate the animal in a more general way, remembering that he has not been designed with any particular reference to the series of rashers into which our grocer has chosen to slice him. We must now look for a different type of law altogether. Two possibilities may arise. We may find that our proposed law, although expressed in breakfast-table parlance, is nevertheless equivalent to a possible biological law; it may be immediately capable of translation into a more general statement which makes no reference to a particular stratification. But on the other hand, it may happen that the suggested law can not be freed from this reference to a particular system of slicing. In that case we can only regard it as approximate, perhaps holding fairly well for the slices of which we have most experience but becoming less and less accurate in the more tortuous parts of the animal. Both of these cases are illustrated in Einstein's modifications of classical theory. Newton's law of gravitation explicitly refers to a space-time frame and therefore to a world stratified into instantaneous states. It proves to be impossible to free it from this reference to a particular stratification without modifying it. In fact if the crucial astronomical observations had shown that Newton's law and not Einstein's was the exact law of gravitation, this would have been evidence of a real stratification of the structure of the world—a stratification revealed by no other phenomena. Einstein's law is the simpler

our operations of measurement, because the appliances which we use for measurement are themselves part of the world. In the earlier part of this lecture we saw that the contraction of the arm turned from horizontal to vertical is not detected by measurements made with a yard-measure which shares the contraction; in the same way any anisotropy of the world does not appear in measurements of it by appliances which, being part of the world, share the same anisotropy. The law of gravitation therefore arises from the fact that a certain type of non-homogeneity and non-isotropy of the world can not come into observational experience, because it is necessarily eliminated in all observations and measurements made with material appliances. The orderly phenomena of gravitation are due to the *absence* of certain conceivable effects. We have been trying to find a key to the mystery; but the secret of the lock lies not in the key but in the wards.

law because it is consistent with what we now know of the general plan of world-structure; Newton's law could only be made possible by introducing a novel and specialized feature—a stratified arrangement of structure—which is not revealed in any other phenomena.

Maxwell's laws of electromagnetism afford an example of the other type. These, it is true, are stated as relating to the particular slices of the world of events, which are served up to us like rashers instant by instant. But they can be restated, without alteration of effect, in a form making no reference to slices. This is a very remarkable property of Maxwell's equations which was quite unknown at the time they were first put forward. It was brought to light much later by the researches of Larmor and Lorentz. In consequence of this Einstein is able to take over the whole classical theory of electromagnetism unaltered; he restates it so as to show how it applies generally and is not bound up with the purely terrestrial point of view, but he does not amend the laws. He metes out different treatment to the gravitational laws and electromagnetic laws, because he finds the latter already adapted to his scheme.

If I have succeeded in my object, you will have realized that the present revolution of scientific thought follows in natural sequence on the great revolutions at earlier epochs in the history of science. Einstein's special theory of relativity, which explains the indeterminateness of the frame of space and time, crowns the work of Copernicus who first led us to give up our insistence on a geocentric outlook on nature; Einstein's general theory of relativity, which reveals the curvature or non-Euclidean geometry of space and time, carries forward the rudimentary thought of those earlier astronomers who first contemplated the possibility that their existence lay on something which was not flat. These earlier revolutions are still a source of perplexity in childhood, which we soon outgrow; and a time will come when Einstein's amazing revelations have likewise sunk into the commonplaces of educated thought.

To free our thought from the fetters of space and time is an aspiration of the poet and the mystic, viewed somewhat coldly by the scientist who has too good reason to fear the confusion of loose ideas likely to ensue. If others have had a suspicion of the end to be desired, it has been left to Einstein to show the way to rid ourselves of these "terrestrial adhesions to thought." And in removing our fetters he leaves us, not (as might have been feared) vague generalities for the ecstatic contemplation of the mystic, but a precise scheme of world-structure to engage the mathematical physicist.

FAST AND FAMINE

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IN a strict sense an organism experiences inanition whenever it subsists on material previously stored in its tissues. Such a contingency may be forced upon it by circumstances or may be embraced through a voluntary impulse. As a deliberate act of total abstinence from food, inanition possesses elements of dramatic effect. In primitive times it was a sign of miraculous and supernatural gifts attributed to the faster, shedding glory of heroism on his deeds. Founders of religious movements were wont to fast for long periods, which doubtless enhanced their prestige for leadership and sanctified their commandments. As a biological phenomenon, however, inanition presents little of either the spectacular or of the heroic, and as a sociological fact it is common and insidious in its effects.

It is erroneous to suppose that during inanition the processes of nutrition are interrupted. Obliged to subsist wholly or in part on accumulated reserves contained in the tissues, the fasting organism is nourished just as truly as if it lived on the fat of the land. But now it is being nourished from within, not from without. Fed or starved, the living organism is governed rigorously by the law of conservation of energy. To maintain its body temperature, to perform vital functions (heart beat, respiration, secretion, etc.), to produce mental and physical effort the potential energy of food-stuffs must be transformed into the various forms of kinetic energy. The organism can not create either matter or energy, and failing to find this from without must use up its own potential energy. Every organism contains in its tissues a source of energy in the form of rich deposits of nutritive substances, which constitute the common foods when they serve to nourish another organism. Thanks to these large deposits, the existence of an organism is not readily endangered through abstinence. Since the metabolic processes obey the usual physical laws, inanition must be regarded as a special—perhaps, the simplest—form of nutrition.

The three chief objects of nutrition are to furnish matter for organic growth and repair of incidental wear and tear of the tissues, to supply energy for maintenance and energy for work. These objects are likewise attained under the conditions of inanition.

Active growth and regeneration are not incompatible with inanition, and the wear and tear, at least in some organs, is so completely repaired as to evade for a long time the effect of nutritional stringency. Inanition does not preclude the ability for extreme and sustained exertion.

According to the mode of origin we can distinguish three types of inanition: First, physiological inanition, which is a normal, regular occurrence in nature. This type of inanition constitutes usually a definite phrase in the life cycle of the animal. In the life of certain animals it also appears as a regular seasonal event or it accompanies the periodical recurrence of sexual activity. Next, pathological inanition of various degrees of severity associated with different organic derangements. It may result from some obstruction of the alimentary canal (esophageal stricture), from an inability to retain food (vomiting), from imperfect utilization owing to rapid elimination (diarrhea), from excess destruction of body tissues (infectious fevers), or from refusal to take food either because of loss of appetite or mental disease. Considering the many variations of inanition possible, it is not venturesome to say that nearly every disease presents a case of pathological inanition. Finally, there are a number of instances of abstention which for convenience may be grouped under the designation of accidental or experimental inanition. In this category, of course, belong all individual experiences of fasting which have been the subject of carefully conducted scientific investigation. Indeed, our knowledge of inanition is derived almost exclusively from laboratory observations.

Under the condition of total abstinence the organism depends largely upon its reserve material. This condition, however, is neither the most common nor the most important aspect of inanition. Profound alterations in the metabolic processes are occasioned when the organism is deprived of some peculiar—though quantitatively insignificant component of the diet, or when the food fails to supply matter and energy according to the actual demands of the organism. In the last case, especially, the reserve deposits of the organism will be insidiously exhausted. It is obvious, therefore, that we must discriminate between complete, partial and chronic inanition.

When inanition assumes the proportions of a mass experience we are no longer confronted with a purely biological phenomenon. Inanition becomes a sociological problem. The biology of inanition has the same significance for the sociological problem as the physiology of nutrition in general has for the economy of national feeding. The information gained from a study of the individual furnishes a most valuable basis for grasping the significance of the

problem and serves as a dependable guide in the search of a rational solution. In either case, however, the sociological condition is not merely a multiplication or a summation of individual experiences. As a sociological phenomenon, therefore, inanition presents a distinct and much more complicated problem. One can not intelligently deal with this aspect of the problem unless the fundamental fact is grasped of the influence of the economic forces in grouping individuals into classes living under a distinct social environment.

As a physiological phenomenon, inanition is invariably of the type of complete abstinence, the nutritive deposits of the organism furnishing the only source of energy and matter. Animals which experience inanition periodically have developed, probably through adaptation, a tendency to acquire during the feeding season large stores of fat. Physiological inanition is frequently of very long duration, for which a large supply of nourishment is indispensable. In hibernation, owing to the very low degree of metabolic activity, the nutrient deposits are used up sparingly, but physiological inanition may also be associated with vigorous activity.

Under pathological and accidental (experimental) conditions we encounter inanition in its numerous variations, ranging from total abstinence to some specific dietary deficiency. Chronic inanition, occasioned by the failure of proper balancing of the organism's demands and supplies, and partial inanition, determined by lack of some element vitally important for the normal functioning of the organism, both underlie many pathological states. A number of diseases have been traced in recent years to specific substances (vitamins) wanting in the diet, and must be regarded as cases of partial inanition. Chronic inanition, on the other hand, is a common physical basis of many ills, like dyspepsia, general debility, loss of nervous stamina, depression and fatiguability, neurasthenia, all of which flourish in the organism whose reserves have been persistently and insidiously sapped.

Strictly speaking, chronic and partial inanition are primarily laboratory occurrences. By this is meant that inanition of a definite type can generally only be produced under conditions amenable to experimental control. Inanition as a social phenomenon is, as a rule, neither simple nor definitely circumscribed, though one finds such instances, too. In certain social strata it would be impossible to determine whether the population suffers from chronic or partial inanition in the sense attributed to these terms. Among our industrial population the earning capacity and the cost of provisions are not adjusted with the sole view of producing for them the necessary quota of energy. This adjustment is left wholly to the precarious workings of the law of demand and supply. It is pro-

verbially true that this adjustment is neither quick nor prejudicial in favor of the economically dependent class. Chapin's report on the standard of living among workingmen's families gives ample evidence of widespread undernourishment. The actual conditions must be much worse than one gathers from the report because the undernourishment is calculated on the basis of food purchased. This leaves out of consideration a very essential factor, namely, the nutritive quality of foods sold in the poor sections of our cities. Where parsimony cuts down on quantity it is practically certain that the dietary quality is likewise degraded. The result is a combination of chronic with partial inanition. From a sociological point of view, abstinence from food is practically unimportant, while the ever present and common partial and chronic inanition blend into the insidious destroyer of life and happiness—the dreaded malnutrition.

Abstinence under compulsion of circumstances is fortunately a rare thing. It belongs in the sphere of accidents, and the suffering it produces is probably as much due to panic as to hunger. Where the abstinence is self-imposed by voluntary choice, and there is nothing in the way of interrupting the fast at any moment, the presence of hunger pain is generally denied by the faster. Were the sensation of hunger in inanition completely dulled it would be difficult to account for the fact that starved animals resume feeding at the first opportunity. We should also fail to comprehend the compelling force of the hunger urge which has been the great factor in all migrations, both human and animal. The question naturally obtrudes itself as to whether or not the sensation of hunger persists during inanition. Clearly one must differentiate between hunger and appetite. One is a primitive sensation common to all living organisms, the other doubtless is an acquisition depending on the degree of mental development. It seems improbable whether civilized man really knows the sensation of hunger. He takes his food in conformity with an established custom at stated intervals and irrespective of his actual needs. His whole existence is a cultivation of habits, and the change of habit is always apt at first to cause discomfort and a feeling of want. Irish or Bavarian peasants accustomed to their bulky diet of potatoes and bread suffer greatly when they are given a small quantity of highly nourishing food. Likewise, persons who have habitually underfed themselves are much discomforted when they are put on a sufficient diet. Appetite and subjective feeling are evidently unreliable guides in the matter of nutrition.

Hunger, on the contrary, is an instinctive demand for nourishment akin to the sex craving. The former is concerned with the preservation of the individual, the other with the preservation of

the race. Hunger is a powerful urge common to all organisms irrespective of their degree of evolution. It is probably as strong in the protozoan as in the rapacious beast of prey.

The mechanism of the hunger sensation in the higher animals has been elucidated by the brilliant researches of Cannon and of Carlson. The sensation of hunger and the subsidiary symptoms—epigastric pain, faintness, nausea—are associated with periodic tonic contractions of the empty stomach. The objective method of recording these gastric contractions reveals that the rhythmic tonic spasms generally associated with the painful hunger pangs continue unabated, or may even become accentuated, during inanition. This important fact has been disclosed by Carlson's collaborators in experiments with dogs, rabbits, frogs and turtles. Carlson himself demonstrated the persistence of strong tonic contractions reverberating through the conscious processes of a human subject who fasted fifteen days, and in his own person in a fast of shorter duration. It is nevertheless a fact not to be disregarded that whenever fasting has been practiced for therapeutic purposes and in the case of the professional fasters the hunger pain and discomfort disappeared after the first several days of inanition. It is difficult to reconcile the lack of desire for food and hunger with the persistence of the hunger contractions. In the diseased organism this may perhaps be accounted for on the assumption that the hunger contractions are inhibited through the bad taste in the mouth. In a number of diseases the absence of contractions has been experimentally demonstrated. The author's own experience has been that he can endure a brief fast of a few days without the least discomfort when he is not feeling well, but in a healthy condition the reaction has always been extremely painful. It is indeed very doubtful whether a healthy individual, with a vigorous demand for nourishment, would willingly endure the hunger sensation unless he was dominated by some powerful emotion. The bravado of the professional faster, the auto-suggestion or fixed-idea of the protagonist and neophyte of the faith of the all-curing potency of inanition, the sublime egotism of the martyr, may all prove effective in actually inhibiting or at any rate masking the hunger pain. Strong emotions, such as anger, fear, worry, excitement, exercise a strong depressing influence on hunger sensations. An over-refined estheticism of appetite may also act as a deterrent to the instinctive craving for food. One should not forget that inanition may result from just such emotional conditions. On the other hand, an exacerbated hunger sensation will completely dominate the conscious processes. Spurred by hunger, animals become daring and aggressive and forget fear. Human beings likewise quickly

unlearn the gentle arts of social intercourse under the urge of the hunger whip. They grow cantankerous, egotistical and brutal.

We know of no factor more potent in completely repressing the hunger urge than the sex emotion. It is a familiar fact, of course, that children at puberty lose their appetite for food. Love and passion in full bloom may also occasion protracted undernourishment. Niclot, in an interesting discourse on the expression of love in ancient literature, refers to the type described by them as "consumptive love." The victim of the passion was thought to be under some supernatural spell. According to Theocritus the physical consequences of this consumptive passion are often very profound. The person fasts for days, and, if his passion meets with an insuperable obstacle, will be reduced to skin and bones. The person becomes the victim of emaciation, progressive breaking down of force, insomnia, photophobia, of an instability of purpose and desire resulting from a disintegration of his will power.

A most striking instance of prolonged suppression of hunger in mammals under the compelling force of the sexual impulse is recorded by Parker. The Alaskan fur-seal bull neither eats nor drinks for about three months in the year, during the entire breeding season. This is the more remarkable because at all times the seal are within reach of food. Living in a state of great excitement, fighting off intruders, chasing mischievous "bachelors," keeping jealous guard over his "harem" of cows, the sexually hyperactive bull experiences complete inanition. Parker relates that "by the middle of June the great majority of the full-grown bulls have established themselves on the beaches to await the coming of the cows. At this stage the bulls are in marvelous form. Their pelts are heavy and firm and their bodies in prime condition. In weight they are not far from 400 pounds. They seem to be possessed of inexhaustible energy . . . Many of the bulls have been on the beaches from May, and during that period between the time of their arrival and the end of July or early part of August, they touch no food. This fast of well over two months coupled with their incessant activity drains them of all their stored energy. Their fat disappears, and they are reduced to almost skin and bones."

Acute inanition as a voluntary act is practiced either by professionals as a feat of endurance, or by crank reformers who see in inanition a panacea for all ills of the flesh. Laboratory experience with fasters as well as long fasting among followers of certain religious sects proves that no harm can befall the healthy individual who abstains from food. The vigorous individual has a thoroughly healthy disregard for all problems of nutrition and is not likely to indulge in fasting as a pastime. Indiscriminate fast-

ing, however, of patients whose strength is already impaired ought to be discouraged. In the hands of the skilful practitioner total abstinence from food may prove a wonderfully effective weapon in restoring health. The therapeutic value of inanition, however, should be studied experimentally and not be left to the judgment of amateur enthusiasts. The practical value of inanition will never be fully utilized until both the lay and the medical profession lose their instinctive fear of fasting. The experiences of recent years which through the medium of the press have reached a large audience will in course of time alleviate the entirely unjustifiable fear of abstention from food for longer periods.

The biological fact that under inanition it is the weakest parts of an organism which are the first to undergo destruction and are eliminated from the body may be safely put at the foundation of the therapy by this means. It is doubtless true that it is a rational therapy in affections of the alimentary canal. Through its tendency to lower the body temperature, inanition would be especially valuable in inflammatory involvements of the gastro-intestinal tract, as in typhoid or diarrhea. Guelpa was among the first to appreciate the importance of inanition in the relief of diabetes. The system now scientifically established by Allen is generally recognized as an effective means for combating this disease.

Since emaciation frees the organism of the excesses of inert material in its tissues, it is often a great boon. The study of physiological inanition should dissipate all terror of a possibility of endangering existence. Laboratory as well as clinical experience corroborates the rejuvenating effect of inanition. If not too prolonged, inanition is distinctly beneficial and may be useful in overcoming somnolence and lassitude as well as in improving the fundamental organic functions (circulation, respiration) muscular strength, or the acuity of the senses. To understand this beneficial influence we may imagine the organism as a wayfarer starting on a long journey provided with a load of victuals. Crouching under his heavy load, he trudges along slowly and with difficulty. His heart is overworked, his respiration is forced, and every obstacle in the road quickly wears him out. Gradually his supply of victuals is consumed and, as the burden becomes smaller, his step grows lighter. He advances more quickly and overcomes obstacles more easily because his muscles are less fatigued. The organism's efficiency improves in a similar manner when the excessive load of inert material in its tissues is used up. The training of athletes bent upon creating a high degree of strength and endurance is likewise concerned with a reduction of the inert fat deposits and a simultaneous building up of the muscle mass. The salmon furnishes us another interesting example. At the time they commence

to migrate from the sea towards the streams their muscles are thoroughly encumbered with huge masses of fat. Fasting all through their long journey, which lasts many weeks and months, they are in a much emaciated condition when they get to the upper reaches of the rivers where the currents are rough and swift. Freed from the fat, however, their muscles are now agile and nimble, and it is at this time that the salmon display marvelous endurance and skill admired by all sportsmen, in progressing steadily against all the odds of the tumultuous current, water-fall and obstructions.

Except where it occurs in nature, acute inanition is primarily an individual experience. Therapeutically it will remain relatively unimportant until education overcomes the innate fear and distrust for the method, and from a sociological standpoint it is practically of no significance. Where it affects large masses, however, inanition is a corollary of certain evils deep-rooted in the social organization; it is an unwelcome and perpetual visitor in the homes of the lowly, but it is not the beneficial agent we spoke of. Here it appears as the insidious malnutrition which silently saps and undermines the health of the mass. It does not signalize its presence by engendering a violent urge for food; it just corrodes the powers of resistance, remaining unnoticed often until the wreck it causes is hard to redeem. It does not kindle up the latent hunger instinct to defy fear and hazards; it blights ambition and gnaws away the threads of social ties by generating an irritable, cantankerous predisposition.

Frequently malnutrition results from nothing else than ignorance. The lack of comprehension that the law of conservation of energy applies to the functioning of the living organism is doubtless responsible for the fact that some deluded folk either reduce their consumption below actual needs of their body, or else consume stuffs entirely inadequate from a physiological standpoint. Generally under such circumstances their vitality is nibbled away by slow starvation. Insufficient consumption of nourishment gradually becomes a vicious habit. The dulled state of the psychic mechanism of appetite and the discomfort actually experienced from taking larger quantities of food are mistaken for the true sign of the organism's demands. The enfeebled appetite misguides the undernourished person to scrimp still more in his diet. The physical consequences of this malnutrition are the great depression of bodily activity, general disinclination to exertion, easy fatigability, as well as anemia and poor circulation, neuritis and various neuroses. It is also a well-recognized fact that the undernourished individual craves for every kind of stimulant, a matter which gains considerable importance when the malnutrition extends to large groups of the population.

One can derive much hopefulness from the fact that the effects of malnutrition, if early recognized and combatted, are evanescent. With proper care and abundant nourishment the organism can be built up again. In his official report on food conditions in Germany, Professor Starling ascribes the collapse of national resistance to the circumstance that the urban population (more particularly, the working people) was starved, and this generated widespread apathy, listlessness and hopelessness. He expresses the opinion that this population of Germany would have to be nursed back to health just like a sick patient and that at least "one or possibly two generations must pass before Germany can recover her former efficiency."

A new and serious source of malnutrition has arisen in our modern industrialized civilization. By the implacable economic forces women have been drawn away from their traditional place in the home into the turmoil of industrial production. At the same time the factory has intruded itself into the home and has preempted much of the woman's function of preparing the family's food. The manufacture of foods dispensed in cans and ready to be served has insinuated itself into the homes of the people to such an extent that it has become literally true that many households can nowadays be conducted with the aid of two implements—the corkscrew and the can opener. The evil of these industrial conditions is not only in the circumstance that the younger generation is deprived of proper maternal care, but also in the fact that tinned goods, when these are the staple article of diet, owing to qualitative deficiencies, may produce the effects of partial inanition. A better understanding of the fundamental principles of nutrition would perhaps offset this danger to the health of the population.

However, ignorance of the essentials of the physiology of nutrition is not the only nor the gravest peril. This can more or less be overcome effectively by disseminating information. Unfortunately, the great peril of malnutrition is rooted much deeper in poverty coupled with ignorance, and against this conspiracy the spread of the gospel of nutritional science can accomplish little. Furthermore, as a social phenomenon malnutrition is not simply a matter of either insufficient or improper nourishment; it is the sinister combination of blighting influences of poverty—overcrowding, underclothing, an unhealthy and unhygienic environment. Here is the fertile soil on which tuberculosis reaps its ghastly harvest.

Visiting Germany immediately after the collapse in the late war, Harris was impressed with the blessings in disguise which the few lean years have brought to the people. He found that there was a striking decrease in the number of patients suffering from

chronic nephritis, chronic ailments of the stomach and liver, from Bright's disease and diabetes. He was generally informed by practitioners that they "did not have gout any more in Germany." Had Harris looked at the matter from the perspective of the sociologist, he would have noted that frugality benefited a class of people with whom eating was generally a social grace if not a central interest in life. The diseases mentioned are proverbially the price paid for the social privilege of overeating. As for gout—a well-recognized rich man's disease—this has always been a badge of class distinction. The reduction of the diet of the chronically overfed population to the limits of a healthy and normal basis has very evidently been a benefit. But in the lower strata of society, where the population lives in the precarious region of the minimum requirements, the increased stinting in nutrition manifested itself quickly in an appalling spread of malignant tuberculosis, especially among children, in increased death rate and general physical degradation. It is of this working population of Germany that Professor Starling says that it would have to be nursed back to health and physical efficiency.

A striking example of wretched physique resulting from the wretchedness of living conditions is presented by the Jews of Poland. Their physical strength, their muscular power has diminished in each succeeding generation; their blood is poor; their stature is small, shoulders and chest narrow. Many have an emaciated, pallid look and even show signs of racial decline and degeneracy. Held back by various disabilities, crowded in the Jewries of Poland, with limited opportunities for gaining a livelihood, they have literally been the victims of malnutrition for generations. Their poor constitution, physical frailty and stunted growth make them manifestly unfit for heavy work. Leroy-Beaulieu says of them: "Few races have so many men who are misshapen and deformed, disabled, or hunchbacked, so many who are blind, deaf-mutes, or congenital idiots." Close inbreeding owing to marriages between near relations can hardly be held responsible for this physical degeneracy. The inbreeding only accentuates the evils of age-long confinement, of lack of exercise, of lack of pure air, of lack of healthy social environment and above all else of wholesome nutrition. The rôle played by malnutrition in producing racial deterioration of the mass of Jews, especially in the Polish ghettos, can best be appreciated from the fact that investigation of their living conditions has shown that they were so poor that for generations they subsisted upon nourishment below the actual minimum requirements. Tchubinski actually found that the Jews of Little Russia and Poland consumed less food than either their Greek Christian or Polish Catholic neighbors.

Transferred to a less forbidding environment, the inherent recuperative powers of the organism under favorable nutritive conditions show remarkable effects already in the first or second generation.

The influence of religious fasting upon the health of the population is little realized. The complete inanition practiced by individual devotees or even by whole ascetic sects is of no concern in this connection. From the point of view of physical deterioration it is the malnutrition associated with religious custom that should be mentioned. Even in this respect the effect is different in different classes of society. In the Middle Ages it seems that the rich men could forego fasting and obtain absolution for a price. Mass starvation from religious devotion is an important phenomenon in Greek Catholic countries. Considering that three days in the week are fast days, besides several protracted fasts at various seasons, it is safe to say that fasting is prescribed for about one half of each year. The fasts might be a benefit if they only limited the consumption of meat. In the Greek Catholic Church, however, the prohibition extends also to eggs and dairy products. As usual the poor population is especially the sufferer under these restrictions. The young children in particular are the victims. Medvedjev found that the boys and girls of school age all show a loss of weight during the fast seasons. The malnutrition of the mass of the people is so great that women are unable to nurse their babies, and there is usually an enormous mortality among the infants. Scurvy and pellagra, eye-diseases (night-blindness?) and typhoid are common incidents among the fasting population. Alcohol was consumed in unusual quantities by the poor people to still the constant irritation which marks their malnutrition. The peasantry deadened itself with drink.

Famine is the most acute form of malnutrition. It is truly one of the cruelest scourges of mankind. It would be impossible to estimate the extent of damage in terms of physical suffering and ruin. Those who fall by the wayside are soon enough forgotten, but famine leaves a trail of human derelicts, of cripples, of blind and feeble, of a generation with undeveloped sinews and brain. The fundamental cause of famine is in all cases probably economic, but crop failure is the immediate cause of the situation when millions of people are without means of subsistence. Those who write about famine vary in their opinion as to whether this is punishment meted out by an unpropitiated god or should be laid squarely at the door of ignorance and oppression, greed and exploitation. In certain countries famine is practically an endemic occurrence. And, strangely enough, the classical lands of famine are also under

foreign dominion, like Ireland and India, or under a tyrannical exploitation as Russia was in the time of the Czars. In India famine played a more momentous and at the same time more tragic part than either war or pestilence. It spread at times over many thousands of square miles, affecting at once millions of people. Since its domination by the East India Company and in the subsequent fifty years under the Crown, India suffered twenty-two great famines and a number of less extensive scarcities. In the great famine of 1876 alone about five and a half million people died in excess of the usual death toll, though, of course, it would be altogether impossible to discriminate how many deaths were directly due to starvation and how many to various diseases brought on by severe malnutrition.

Famine is not merely destructive of health and physique: it is in a still greater degree a disrupter of morale and character. In the sharp struggle to maintain life all scruples are overcome, neighbor is against neighbor, and the strong are ruthless towards the weak. With wonderful force of simplicity does a thirteenth century Russian chronicle relate the horrors of the famine in the Novgorod province: "We were all in a fury of irritation; a brother rose against his brother, a father had not pity for his son, mothers had no mercy for their daughters; one denied his neighbors a crumb of bread. There was no charity left among us; only sadness, gloom and mourning dwelt constantly within and without our habitations. It was a bitter sight, indeed, to watch the crying children, begging in vain for bread and falling dead like flies."

The aftermath of famine, however, is still more appalling. Little actual information can be gathered of the after-effects. Prugavin tells of the many thousands of peasants afflicted with scurvy, typhus, spotted fever, influenza and diarrhea in the terrible famine which spread over the central provinces of Russia in 1898. Even long afterwards nearly all the children from the famine area suffered from various eruptions, rickets, diarrhea, purulent inflammation of the eyes. The doctors who went into the pestilential districts to bring succor to the famine victims have noted the unusually large number of people with severe eye diseases. The great Irish famine of 1848 likewise left a trail of blind men and women in its wake. Dr. Emmet reports that the number of blind increased from 13,812 in 1849 to 45,947 in 1851. The recent developments of the science of nutrition have shown that such affections of the eyes are invariably associated with the lack in the diet of a substance known as vitamin A, and its absence is a concomitant of malnutrition.

ZOOLOGY AND THE COLLEGE CURRICULUM[1]

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EVERY teacher of zoology must at times experience a feeling of dissatisfaction with the status of this subject in the general educational system, or if not with its status in the educational system, then with the almost total ignorance of the public regarding it. For whereas animal life furnishes one of the largest factors in man's environment and certainly one of the most intensely fascinating factors, one finds but small place or none at all given to the subject in our high schools and a comparatively small interest taken in it in our colleges and universities, while in our graded schools few of the teachers attempting to teach it as nature study really know enough about it to make their work dependable or desirable. And accordingly we find the general public so ignorant of the subject that it becomes the victim of all sorts of pernicious yarns and trashy animal stories which, in the credulous, fire the imagination to a point of irresponsibility, while in the critical they dull the mental appetite to a point where the mere mention of the subject is repulsive.

This seems a strange predicament in which we, who are attempting to lead forward along the trail first blazed by such men as Linnæus, Schleiden, Schwann, Lamarck, Agassiz, Darwin and their like, find ourselves. And I pause to ask you why we of the twentieth century, who have more to look back upon, more to look forward to and more to work with than all that have lived before us, are in spite of these great advantages unable to make this large and most interesting of all subjects so appeal to the good sense of the people as to receive at least its proportionate share of attention in the curricula of our universities and from the students of higher education.

I have taken the trouble to inquire of a number of our leading universities as to what percentage of their total enrollment takes at least one course in zoology. And according to the replies received the percentage ranges from 3 per cent. to 27 per cent. with an average of about 13 per cent. This means that about one in

[1] Read before the Kansas Academy of Science, February, 1921.

eight of our supposedly educated men and women have during their educational career made at least some study of animal life. My first question is: Shall we agree that the world of animal life is of such minor importance that seven out of eight of our educated public should not even be instructed in the primary elements of the subject? And second, if it is not so unimportant, why do so few study it? It seems to me that it is up to the teacher of zoology to answer this question.

When we consider the relationship that exists between zoology and sanitation, hygiene, medicine, agriculture, horticulture, forestry, household economy and between zoology and recreation, we conclude that from the practical viewpoint it is important that the average student should study animal life. And when we consider the relation of the scientific method in zoology to the history of thought we are sure that ministers and teachers should be familiar with the subject. Looking at the wealth of recreational enjoyment and the cultural aspects of a knowledge of animal life we wonder that any student is content without it. And yet the fact remains that only one in eight of our students studies zoology. The cause for this lack of interest in zoology is, I think, not difficult to discover. The general course as given in our colleges and universities is primarily designed to meet the needs of two classes of students, *viz.*, those who are preparing for research or teaching and those who are preparing for the medical course. Such a course must of necessity be quite technical—too technical to appeal to the average student who is looking forward to a career in one of the commoner vocations, such as agriculture, commercial life, home-making, etc. (And yet we all know that a knowledge of animal life is of great importance in the educational equipment for any of these vocations.) But we find our departments sought out by the premedicals, prospective biology teachers, a few unusually broad-minded students of agriculture and practically no others.

Now from the zoologist's point of view there are about three objectives which justify the teaching of zoology: First, the research objective or the preparing of investigators who shall extend our knowledge of animal life; second, the economic objective or the preparation of men for the field of applied zoology, and third, the cultural objective or the equipping of men and women for a larger and fuller appreciation of the organic world about them—an enriching of life, the making of a better and more intelligent citizenship.

These three objectives are very closely related, for there is little value in extending our knowledge of animal life unless it may eventually lead to an application of such knowledge to the problems

of human welfare, either in an economic or in a cultural way, while both the economic and the cultural objectives are dependent upon research for their greatest achievements.

Now let us examine fairly for a few minutes our system of teaching zoology in its relation to the needs of students. Student No. 1 comes who desires to become a research zoologist or a teacher in a university. We start him in our general course and then he passes through one advanced course after another of morphology, histology, embryology, cytology, etc., until we turn him out a finished product ready to enter his chosen field. So far we are all right. But this class of students is small, representing probably 5 per cent. or 6 per cent. of the student life which comes under our tuition. Student No. 2 comes, representing perhaps 50 per cent. to 75 per cent. of our student life. The desire of this student is not to become a specialist but merely to prepare for a larger and broader life in one of the commoner vocations, perhaps to be a merchant, a housewife, farmer, lawyer, minister, salesman, banker, a musician, a painter or to enter any one of a score of other vocations. The needs of this student will be met by a study of the general principles of zoology in a not too technical way, a study of habits, habitats, animal associations and relationships, and the natural history of the local community, state and nation. We have but one thing to offer and that is our general course which is adapted to the needs of the prospective professional few. We can hardly expect a prospective merchant, for instance, to elect a course primarily designed for the medical profession, and yet we know that zoology in its broader aspects has much to offer even a merchant. But, not desiring to wade through the maze of dry details, this student who represents the bulk of student life turns away and studies no zoology at all. Next comes student No. 2 who purposes to prepare for work in applied zoology. He may become an entomologist, an animal breeder, a sanitary engineer or some other specialist whose work is wholly or in part founded upon zoology. For this student we have courses suitable and in due time he has gone under the tutorage of the specialists in his chosen line and comes forth prepared for his work. But here he faces a new difficulty. Two conditions are necessary to the successful application of scientific knowledge: First, a prepared specialist, and second, a responsive public. We have met the first condition, but the second we have not met, and when our young specialist goes into the field he finds himself surrounded by a suspicious and superstitious ignorant public who lack just one thing to make them his enthusiastic supporters and that one thing is knowledge—a knowledge which is lacking largely because

when student No. 2 came to us we had nothing to offer but a specialist's course and so he turned away.

Speaking from the standpoint of one who has had some little experience in three different states as a practical demonstrator, I submit to the practical specialists who may read this the proposition that were it not for those very few farmers and others whom you find in the various communities who have some special knowledge of the subject in which you are working, the demand for the services of a specialist would indeed be small. And let us not forget that only one in eight of our *university trained men and women* acquire this knowledge while with us. So we see that one of the weaknesses of our system is that it results in a sort of professional suicide.

And this suicidal tendency is not limited to the realm of applied zoology, for when our high school teachers go out with only their technical training they not infrequently find themselves unable to successfully present their subject to boys and girls who are eager for a knowledge of natural history, but not capable of attending on those phases of the subject which are so often presented to the exclusion of more fascinating aspects which may be equally scientific. And to me it seems unfortunate that so few of our high schools offer any work whatever in zoology. The general science course does not make up this deficiency, for it attempts so many things that it must of necessity consist mostly of "general" and but little of science.

Zoology furnishes a world of interesting and practical material of sound worth both from a cultural and from a practical viewpoint. And I firmly believe that the subject is so important in its relation to human life that the majority of the students of our colleges and universities should take a minimum of six credit hours in the subject, out of the 120 hours required for the A. B. degree. I do not believe that this should be a requirement, but I think that the subject should be made to appeal to the average student as a necessary part of his or her equipment for life.

And now arises the question: How can the subject be taught so as to meet the needs of the general student and yet not sacrifice those technical qualities which are so essential to the professional zoologist? In answer to this question I wish to suggest a line of procedure which is slightly different from that usually followed. I believe that in order for our department to function properly there should be established two different elementary courses in zoology, the one preparatory to research, medicine and applied zoology, and the other designed to give a cultural and practical knowledge of the subject such as would best serve the needs of the men and women who enter those vocations which employ the bulk

of our citizenship, such as merchants, agriculturalists, housewives, lawyers, salesmen, grade school teachers, ministers, lecturers, etc. The former might be much the same course as now given in most colleges or like that outlined in Dr. Shull's new text, while the latter should deal with the same principles in a more general way and should treat much more at length the subjects of distribution, habitat, habits, animal associations, taxonomy of the familiar forms and questions of economic relationship. This course should present a greater mass of material than is presented in our present general course, but should require less of a technical nature. *It should not be an easier or lighter course but merely of a different nature with a different purpose.* We need no less of the technical but we do need more of a general knowledge of animal life and we need to make this general knowledge reach a far greater number of people. We need to develop in a larger number of people a proper respect for the scientific method in thought and in living. We need to train more people in the art of finding proper recreation in the out-of-doors. I believe that there is a very definite relationship existing between these phases of the subject of zoology and *good citizenship.* And whatever may be the secondary and tertiary aims of higher education its primary aim must always be that of developing the highest type of *citizenship.*

To the professional zoologist it is important to know the chemistry of certain metabolic processes in certain animals, but to the average university graduate it is more important to know the feeding habits and home life of those same animals and their relation to his interests. If we are to raise zoology to its proper place in the college curriculum we must raise it to its proper place in the lives of those whom we teach; and to do this we must realize that it is just as important that a college graduate know the difference between a nuthatch and a sapsucker as it is that he know the difference between a chemotropic and a thigmotropic reaction. In a very widely used college text-book on zoology and one which may be taken as a type, thirty-six pages are devoted to the phylum coelenterata. Of this amount approximately one page is given to the discussion of coral reefs and their formation and six lines are devoted to the "economic and geological importance" of the group.

In another very recent and to my mind a very excellent text the author has seen fit to append a glossary of 1,237 technical and historical terms which are used in the volume. I presented this list to two college freshmen who had made grades slightly above the average for their class in a standard intelligence test. They had both finished the first semester's work of their freshman year,

and my test proved that they *thought they knew* the meanings of 314 and 354 words respectively out of the list of 1,273, and in looking over the lists of words whose meaning they felt they knew I noted that a large part of them we had used in a course in physiology during the first semester of this year.

On the basis of these findings it would certainly be conservative to say that a freshman beginning zoology would have to deal with a thousand new and technical terms in the mere reading of this text. I am not going to say that this is too much to ask of a student looking forward to a professional career in a field where a vocabulary of technical terms is necessary; but I do say that the mastery of such a list will leave but little time for the acquisition of facts and the grasping of principles which are of so much greater value to the *average* student than at least half of these terms would be. I am not trying to condemn our present general course in zoology (though I do agree with some of the current suggestions as to how it may be made better than it is at present). But I am trying to point out what seems to me to be a very great need in our field of endeavor. We surely have two quite distinct problems, and I believe they can only be properly met and solved by attacking them in two different ways.

In my own experience in leading classes in field zoology I have found a large percentage of the general public eager for a knowledge of natural history and I have been surprised at the effort which students and even business men were willing to put forth to acquire that knowledge. The course I am suggesting would furnish a sufficient introduction to the subject of natural history and methods of studying it to satisfy this desire, and would furnish an entrance to more advanced courses in the natural history of the various groups. It seems to me that there is entirely too little stress laid upon this phase of zoology to-day. The great builders of our science have all been men of a very wide knowledge of natural history and therein lay their secret of success as teachers and students of the subject.

It seems a rather serious reflection upon methods when university graduates who have majored in zoology are unacquainted with the habits and relationships of the common animals of their own community. These same students are able to discourse at length upon subjects of histology and cytology, which is well enough, but why not both? I have known zoology teachers in high school holding degrees from our best universities who could not answer the simplest questions about the birds of their own campus and who did not recognize even the orders of common insects brought to them by their students. These teachers were well trained in some phases

of zoology, but should they not be able to carry their study out to where animals live without becoming embarrassed?

The other day in looking through a book on psychology which is the adopted text for our state of Kansas I found a "drawing" (by the author of the text) of the nervous system of a mollusk which is labeled and discussed as that of the earthworm. The author has a Ph.D. after his name; but I am not supposing that he earned it in zoology. The point I wish to make is that our courses are not studied by those specializing in other lines as often as they should be, and I fear we are partly to blame for this. A few years ago I discovered a rather gross inaccuracy in our commonly used text-books regarding the mouth parts of orthoptera, and in tracing it back I found that for fifty years this same error had been copied in one after another of our texts even down to the present day. All of which points to the fact that we are studying books and prepared sections more than we are studying animals as such.

The establishing of such a course as I propose would accomplish five things: (1) It would extend the knowledge of zoology to a very much larger group; (2) it would render applied zoology very much more effective by virtue of the increased knowledge of our subject among the general public; (3) by a revival of the study of natural history we should be led to a study of animals as organisms as well as cells and organs, which would render our work more scientific; (4) by a more widespread interest in natural history the safeguarding of our public parks against the encroachment of commercial interests would be insured; (5) with the increased interest in natural history and the consequent appreciation and upbuilding of public parks a much larger percentage of the public would seek outdoor recreation, which would inevitably result in a raising of our standard of health and in better citizenship.

TOIL AS A FACTOR IN HUMAN EVOLUTION

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THE sphere of toil is more comprehensive than that of modern labor problems and far more primitive. In fact toil dates back to the beginnings of life itself, when the most primitive unicellular organisms toiled to extract a livelihood from the inorganic environment. That the living cell of protoplasm toils at its ingestion, secretion, digestion, assimilation, excretion and many other life processes there can be not the least doubt. And in the same sense that the single-celled organism, both of long ago and of to-day, toils diligently for its livelihood, so also do their compounded, many-celled offspring toil in so far as the myriads of component cells are concerned, even though the resultant organism be the laziest man on earth.

The cell toils in either case, be it single or compound. It is not the fact of toil, therefore, but the nature of the toil which differentiates the lower from the higher organism, the toil of many of the cells in the complex organism being differentiated, or highly specialized, while that of the simple single cell is undifferentiated toil, generalized, or complete in all functions. The primitive man has in his body cells which perform but one function for him, while other cells perform another function, each of these cells, or group of cells, being highly specialized for its own particular task. The primitive man himself, as a unit organism, performs all functions of the living body, and is able to turn his hand or mind or other part to any performance he may choose, be it eating, playing, thinking, speaking, fighting, while many vital processes go on within him unconsciously.

The modern man is more or less civilized, whatever that means, and is battling with himself—or with others—as to how generalized, or how specialized, his work as a complete organism shall be. Shall he perform a varied and interesting group of tasks, bringing body, mind and heart into enthusiastic effort, or shall he specialize in but one monotonous task, repeated endlessly? Shall he be a complete organism himself, or a differentiated unit in a complex social organism composed of many men?

The question of the generalization or specialization of the toil

of the cell has had much to do with the evolution of the human being in the past. The question of the generalization or the specialization of the toil of the entire man will have much to do with the evolution of the future man, and will be considered later in this paper. Intermediate between these two extremes of the problem, we may ask what effect the changing nature of the toil of the animal of the past had upon its evolution into human form.

The nature of the toil of the individual affects his postnatal development quite noticeably. Just what affects his prenatal heredity is a question which constitutes a battle-field royal of scientific controversy, into which men have thrown more heat than light, and over which battle-field the obscure shadows of orthodoxy have shifted now here, now there, as one or another virile leader of thought has gathered his train of followers under the shadows of his intellectual garments, shrouding their more timid natures in the happy obscurity of the orthodoxy he has built about his scientific self even as the priest robes himself in his priestly robes. The orthodoxy of men of science has many times been as inexorable as the orthodoxy of men of religion.

This chance suggestion of science and religion, mentioned only by way of illustration, leads me to make the following brief comment as to the permutations and combinations one finds rung between the two. To-day one may find those who claim to be perfectly orthodox both in religion and science; one finds those who claim to be orthodox in science, but free lances in religion; those who are orthodox in science, and claim to have no religion; those who reverse any one of the before-mentioned combinations; those who are free lances in both science and religion; and those who are moved neither by the spirit of "standing pat" nor the spirit of revolt, but open-mindedly and diligently seek for all light and all comfort from every source, conscientiously rejecting all which is not light. With this comment I will leave the question of religion as a factor in human evolution for treatment in another paper.

All admit that variations are continually occurring within every species, human and all others. Whether the environment has or has not anything to do with the production of those variations, it has something to do with selecting those variations best adapted to itself. So with the animal whose offspring was destined to become man, the nature of its toil, somewhat more intelligent than that of others, must have had much to do with his selection and survival. The greater versatility and ingenuity shown in its toil certainly gave it advantages over its fellows who toiled more as the other beasts had toiled for ages past. However one may explain or leave unexplained the minute links in the chain of cause

and effect, few will deny that the changing nature of the toil of the man to be was at once both cause and result of his current evolution—among the many other causes and results. Other factors may have been of greater consequence than toil, some were certainly of less consequence, for by toil we mean the sum of all activities. In the case of man this included the use of implements and the better provision for safety, shelter and food supply.

Our flying mammals of to-day, the bats, were descended from mammals which never flew. The flight of bats is most strenuous toil, requiring great exertion and rapid physiological metabolism, and is most intimately connected with food-securing. Cut off the wings of bats in nature and they would soon perish. Our large swimming mammals of to-day, the whales, descended from terrestrial mammals of the remote past, depend absolutely upon their swimming powers in all their activities of life. The toil of these blubbery monsters is sometimes prodigious, yet very different in nature from the toil of their landlubber ancestors. The toil of our degenerate parasitic worms, now very erratic in nature, now very primitive, is quite unlike the toil of their more normal, non-parasitic ancestors of the past. Rob them of their chance to parasitize and they die. Man is not the only one that changing toil has influenced.

Continuous changes of toil in the past have been intimately associated with other continuous changes in the organism. In the present and in the future, equivalent changes in toil will be intimately associated with equivalent changes of other sorts in the nature of organism.

Whether one approaches the facts of evolution from the paleontological viewpoint, or from a very broad view of the creatures living to-day, their structure, habits and development, one can but conclude that the nature of the toil of any living organism has had, and will have in future much to do with that organism's evolution. Interesting as is the study of the history of human toil in the past, and its close connection with other changes in the life of our race, it is of even more importance to foresee the consequences to the race which different phases of human toil will produce. The labor problem of to-day is but one sector of a most vital question of toil which is facing us, now menacing our evolution, now smiling on it; threatening to lead us downwards, promising to lead us upward, or chancing to lead us in devious, tangled ways.

While many are working themselves half to death, and more are working strongly and bravely, with profit to themselves and

to others, very few are giving the subject of toil the clear, impartial and comprehensive thought which it deserves.

It is often and rightly asserted that sexual reproduction is one of the oldest vital functions, but toil is older than sexual reproduction. It is as old as nutrition, respiration, excretion—as old as life itself. Standing therefore in the most ancient rank it deserves the utmost consideration.

Old as life itself, the toil of the cells, by cooperation and differentiation, has made the hosts of complex organisms possible. By change, it has made the whale aquatic, the bat aerial, the parasitic worm a lazy, degenerate trouble-maker, the man a fine, free-thinking, faithful, joyous individual, the hymenopterous insect, in some cases, a peculiar, specialized individual, performing continuously a single task in a community. Man has shown slight tendencies to develop along each of these ways, though only recently successful in the air. The tendency to become a human parasite has often made an appearance in historic times, but fortunately has not become wide-spread at any time, except in localities where cretinism has been endemic. Modern industrial conditions urge upon the race, more strongly than ever before, the highly specialized, single task for the individual laborer on the pattern of the hymenopterous insect. Now with all our long and wonderful evolution from the single-celled organism to our present selves, and with all of our powers of cooperation and our love of race, we have succeeded so far in keeping ourselves intensely and roundly and joyously individualistic. And I believe that it is this strong individualism which has prevented human parasitism on any large scale. Our well-developed individualism is also responsible for our lordly spirit and all-conquering ambition, and the many and varied joys which come to an all around man in the world. How then shall we meet the many problems which the present labor situation, and the overcrowded, overcivilized cities are thrusting upon us? Shall some toil only with their brains and others with their hands? Shall some specialize in one single kind of brain work? To me, professionally an observer of the living organisms of to-day and a student of the life of all times, it seems infinitely wiser for every individual to round out his daily activities as perfectly as possible. A powerful and wise man among the ancients tells us to study the ant and be wise; he might equally well have told us to go to the tapeworm and not do as he does. While profiting by emulating the industriousness of the ant, we would lose the best which life has to offer by merging our individuality as completely as some ants have done. Hebrew history describing the ideal conditions of life prevailing under the rule of the wise

man who gave the advice about the ant, records that the people dwelt safely, every man under his vine and under his fig tree all the days of Solomon. This points to an individualism in which every person was something of an agriculturist on his own account. And truly, a small amount of agricultural activity daily would be a most valuable addition to the life of those who have it not. Hebrew prophecy, foretelling the ideal conditions to come, says that in the last days it shall come to pass that they shall sit every man under his vine and under his fig tree. To this every muscular lover of the open will say amen.

The modern science of dietetics has shown the world the value of a balanced ration of food both for man and for cattle. A scientifically balanced ration of activities for man is of even greater value. What should this ration include, and what exclude? Upon the answer to this question will depend our future evolution as well as our present happiness. To answer this question let each select three or four of the most ideal persons he knows or knows about. Let him then think of the several elements entering into the complete, well-rounded life of each of these persons, then add these together, and see what varied activities are necessary to exercise completely and regularly these varied elements of personality. The results will set you thinking, if you have an imagination, and you will next query how you can apply the results to your own benefit. And it is well for each one to think of the enrichment and evolution of his own life, within whatever narrow limits his prenatal heredity will permit. The younger he is when he thinks of this, the greater will be the personal gain, and, if it be not too great a heresy to suggest it, the greater the chance of passing on some slight portion of his acquired gain to his offspring, a slight chance, perhaps, and denied by many.

There is a tendency to-day to make of some a mass of brains and emotions, while causing others to be emotionless hands. While all believe in the superiority of brains over brawn, most would, if they had to choose one or the other, prefer to be a mass of living muscles without any brains than a mass of living brains without any muscles. It would be far less disturbing to the mind.

Watch some of our moneyed New England spinsters as they sit in the parlors or on the piazzas of their favorite New England inns, playing cards, knitting or just gossiping. Some of them are fast growing unable to walk a mile, and must sit in the deep, soft cushions of a car if they would go somewhere. But not all are so, for many are keeping themselves superbly "fit" in body, mind and soul. The whole man needs exercise daily, muscles, lungs, learning power, creative imagination, special interests, sym-

pathy, social interests, artistic tastes, musical, poetical, philosophical, scientific, and any other good tastes which the individual may possess, repressing all the while any morbid or unwise tendencies. This last mentioned elimination of undesirable tendencies is best accomplished, not by thinking of those things which one would eliminate, but by filling the life with such a rich variety of good activities that there is no room for the weeds in the well-planted garden.

While specialization does and will accomplish much which could not be done otherwise, the wise specialist will put a strict limit to the time he devotes daily to his specialty, and plant the rest of his daily activities as wisely as the best of all-round beings.

Adaptability to one's environment is not the panacea it is sometimes claimed to be. Without underestimating the value of versatility, we need only mention the guinea-worm and the cosmopolitan tapeworm as wonderful examples of adaptation to environment. The widely preached doctrine of being contented with whatever state one finds himself to be in may be pressed too far. It is far better to growl a little about your circumstances if growling will incite you and others to set to work to improve your environment. Introspective faultfinding may also start some wheels in motion for improving self by improving the quality and variety of one's activities, which we may call his toil.

Toil considered in this widest biologic sense as the sum of all activities of an individual, becomes an interesting challenge. Realizing its strong reactive powers upon the individual, and eventually upon the race, the spirited individual will exert his faculties to the utmost in securing a regimen of activities which will each day call into most harmonious play all his best powers. Instead of being satisfied to do with his might whatever may chance to come to hand, he will have a broad and very definite plan of action which will make him truly the architect of his own career, and will, at the same time, react most helpfully upon his associates. It seems reasonably certain that the most capable individuals will never be content to specialize to the extent which would convert them into mere elements in a compound or cogs on a wheel. Life for each individual should be a thrilling, joyous, strength-giving composite, supplying the purest air for his lungs, exercise in great variety for all his muscles, and calling into play his highest powers, intellectual, musical, religious and artistic.

The small farm, in combination with some intellectual profession either salaried or independent, will doubtless be the solution which many will try, as supplying both the physical foundation and the mental superstructure. On that same small farm, many,

if not most, of the necessities of life may be produced rather than purchased, and also some luxuries. It is the "vine and fig tree" idea. A few hours of varied farm and garden work, a few hours of concentrated intellectual work, a few hours of recreation and social activity, in the midst of an inspiringly beautiful landscape chosen for its pleasing qualities, and the whole pervaded by a worshipful, devoted spirit within the lucky fellow who had so ordered his life, would seem to round out the day most delightfully along the lines of progressive evolution toward higher and even higher attainments in the life of the individual and the life of the race.

The toil factor in evolution, old as any other factor, is as fundamental as any, and should be given full recognition in any plan for race improvement.

The problem seems all too simple when viewed thus in its entirety, from the beginning of life to the present day, from the single cell to the highest organism, but see how far your own life diverges from a simple, ideal combination of all the more important activities. The true test of your executive ability will come in making the ideal a successful and practical reality.

CITY GROWTH AND CITY ADVERTISING

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IT is a widespread impression in the United States that any live community can remain in its active and populating condition only by an extensive advertising campaign. This notion persists largely, no doubt, because advertising plays such a tremendous part in the merchandising world; and the selling of city advantages, in sites, climate and transportation, appears to be the normal function of many city and town organizations. In a careful analysis of the advertising methods of hundreds of towns and cities, it is fairly evident that advertising has not been a serious study, for in many instances time-worn schemes which have long since served their purposes and some which were never provocative of results, are still in existence. It would be a bold person who tried to answer the questions as to what extent city advertising is economically justified. However, certain inferences may with safety be drawn from the study of the growth of American cities and from the advertising of these same centers. The first part of this paper discusses the growth of the cities of the United States during the last ten years, and incidentally the advertising of these: and the second part is a study of the advertising of the cities, particularly the most extensive advertisers, and incidentally their growths.

CITIES OF GREAT INCREASE: 1910 TO 1920

One hundred cities in the United States had a growth between the years of 1910 and 1920 of 37.5 per cent. or over; twenty-five of these had an increase of over 100 per cent. in this ten-year period; and two of the latter had increases in excess of 1,000 per cent. The greater part of these cities attained their growths because of a single cause; automobile manufacturing, automobile accessories, suburbs, resorts, oil and gas, and so on. The second one hundred cities show no such singleness of cause of growth and the study of the reasons for their increases becomes indefinite; for this reason only the first one hundred are considered here.

A—Automobile centers: Thirteen of the hundred cities owe their increases to the manufacturing of automobiles and to the

production of automobile accessories. The average growth of the thirteen centers was 230.4 per cent. and the individual cities have a range in increase from 1,266 per cent. to 40 per cent. This is the greatest average growth shown by any group of cities in this study. Among the cities in this group will be found Hamtramck, Michigan (increase of 1,266 per cent.), Highland Park, Michigan (increase of 1,028 per cent.), Akron, Ohio (increase of 201 per cent.), Flint, Michigan (increase of 137.6 per cent.) and Detroit, Michigan (increase of 113.3 per cent.).

The value of the product per man in the automobile industries has been as a rule much greater than is the case in the normal run of manufacturing establishments. In 1919 the per capita value in the automobile industry in the city of Detroit was $6,285, while the average in all industries was $3,454. A part of this higher value has been due to wages which has made the automobile cities the Mecca of all workers in wood and iron. It is evident that the country has not reached the saturation point of automobiles, and until such time as this condition is attained, this group of cities will probably go on increasing in ratios corresponding to those recorded during the last ten years. But with Detroit building in 1920 1,250,000 cars, or one car for every nine seconds of the working day; with the Ford Company reaching 100,000 cars a month and a record of 4,688 cars in a single day, it would appear as if the saturation point could not be long delayed. The total gain in population in Michigan during the last decade was 857,049, and 84 per cent. of this gain occurred in the four automobile cities of Detroit, Flint, Lansing and Pontiac.

Cities of this group have received enough advertising from their products and from the favorable conditions of the labor market to enable the city authorities to dispense with extensive advertising of an informational nature. The truth in the case of automobile manufacturing is so impressive that the daily papers and the popular magazines have reported the activities of these centers and have kept them before the public. In general it is safe to say that these are cities of no particular form of active advertising. They may publish a trade board journal. For example, the *Detroiter*, the magazine of that city's Board of Commerce, records the daily and yearly activities of the automobile industries without any attempt at an elaboration. These facts are interesting enough to be quoted extensively by the press, eloquent enough to be appealing and persuasive enough to actually attract not only the manufacturer of automobiles and automobile accessories but to move sufficient labor and capital to these centers to guarantee their continuation and growth.

B—Oil and Gas centers: The second group of cities of which there are eight in the hundred are oil and gas centers. These cities have an average increase in population between 1910 and 1920 of 170.2 per cent. This group might easily be rated with the automobile cities, since the great demand for oil and gas is a direct resultant of the increase of the motor car. Some of the cities of this group are Wichita Falls, Texas (with an increase of 388.8 per cent.), Tulsa, Oklahoma (increase of 296.4 per cent.), Clarksburg, West Virginia (increase of 202.9 per cent.), Beaumont, Texas (increase of 95.8 per cent.) and Fresno, California (increase of 81.1 per cent.).

The centers of oil-producing areas show every sign of being mushroom cities and this is emphasized by the trade organizations in these centers in their vigorous insistence that the cities are stable commercial or agricultural centers, not dependent on oil. Wichita Falls with a population of about 10,000 in January, 1918, ended the year with a population of about 40,000. In July of that year a wild-cat test near Burkburnett, 14 miles north of Wichita Falls, brought in oil; and the tide of investors and prospectors set in toward that city. The advertising of this group of cities is of two kinds—the wild-cat advertising of oil prospectuses, which is the real drawing card of these centers and which accounts largely for their increases and the advertising of the city itself. The wild-cat advertising from the standpoint of the towns involved is free advertising, similar in nature to that of the automobile cities. The second type of advertising of this group is the usual city advertising carried on by the local trade chamber. The tendency in this latter type is to stabilitate the increases created by the wild-cat advertising and to turn the attention of the prospect away from oil—tacitly assuming in the process that the oil trade is transient. Thus the Wichita Falls Chamber of Commerce:

> Wichita Falls is the supply and distribution center for a dozen great oil fields—and yet Wichita Falls is not an "oil town." It is a modern city of commercial and industrial importance, with big manufacturing, retail and jobbing interests that reach out into a trade territory with a radius of 100 miles.
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> While it is true that the discovery of oil brought a great influx of wealth to Wichita Falls, oil did not create the Wichita Mill and Elevator Company, the Wichita Motors Company, or any other of the 45 prosperous manufacturing plants. It is not oil that is responsible for a manufacturing and jobbing business in Wichita Falls of approximately $40,000,000 per annum.

C—Suburbs: This group of cities owe their increase to suburban situations and represent the outpushed surplus population of crowded city sites. Some of the cities of this group are Cicero, Illinois (with an increase of 209.1 per cent.), East Cleveland, Ohio

(increase of 197.3 per cent.), Lakewood, Ohio (increase of 174.9 per cent.), West New York, New Jersey (increase of 120.7 per cent.) and Irvington, New Jersey (increase of 114.5 per cent.). Altogether in this group there are ten cities of the hundred cities of greatest increases, and the average increase for this group is 114.8 per cent.

In all cities of a population of 200,000 or over the suburban areas increased at a greater rate during the last ten-year period than did the centers themselves. The movement from rural to urban districts which has persisted for a number of years became accelerated during the 1910-1920 period, and much of this occurred doubtless during the last five years of this period. These suburban increases were more noteworthy than the census figures show, for many cities have increased their bounds to include the neighboring people and are thus included in the city population rather than in a suburban population. Detroit's jump from thirteenth place in 1910 to fourth place among the cities of the United States in 1920 was aided by an actual increase in area; and another increase may be realized if Highland Park and Hamtramck, islands within the corporate bound of Detroit, yield to the blandishments of the ambitious city. Norwalk, Connecticut (with an increase of 299 per cent.), Bethlehem, Pennsylvania (increase 292.2 per cent.), and Los Angeles, California (increase of 80.7 per cent.), are other examples of increases due in part to enlarging the area. The true city of the suburban type may be illustrated by East Cleveland, Ohio, and Lakewood, Ohio, whose increases are the overflow from Cleveland (increase of 42.1 per cent.). Most of these cities are much less well known than the centers of production of which they are a part. Rarely do they have boards of trade, since they are purely residential sections, and advertising does not enter into their plans. Now and then a suburban site, Cicero, Illinois, for example, builds itself at the expense of the host city by advertising competitive tax rates and attempting to operate on a lower tax basis. Cicero decreased in population between the years 1900 and 1910 by 10.7 per cent.; but between the years 1910 and 1920 the bait of a low tax rate on industrial establishments attracted a few concerns from Chicago with the result that the city stands at the head of the suburban group in amount of increase in 1920. This type of advertising, under the present conditions at least, must be classified as wild-cat advertising.

D—Steel cities: The next group is the steel and steel products cities. Eighteen of these are found in the first one hundred cities and the average increase was 78.3 per cent. Here are found Bethlehem, Pennsylvania (with an increase of 292.3 per cent.), Gary,

Indiana (increase of 229.6 per cent.), Warren, Ohio (increase of 144.1 per cent.), and Canton, Ohio (increase of 73.4 per cent.); further down in the list are the larger cities of Toledo, Ohio, Cleveland, Ohio, Bridgeport, Connecticut, and Erie, Pennsylvania. Bethlehem is rated with an increase of 292.3 per cent., but subtracting the increase due to accession of territory, its true increase was about 53 per cent.

It is an expectable thing to find that this industry, enlarging its plants as it did under the conditions which prevailed during the period from 1914 to 1919, should be the means of increasing the size of the localities where they are best developed; but the abnormality of the times hardly makes any conclusions from these increases possible or safe. It is interesting to note, however, that the cities of this group do not fall into the class of advertising cities. They do have trade organizations which set forth modestly the conditions and advantages of the particular site, but this material is generally distributed by exchange with other similar organizations rather than widely circulated as advertising matter.

E—Resorts: The city groups so far mentioned do not follow any regular and persistent advertising plan. Some of them write that they do not advertise at all, as they do not need to do so. Seven of the cities in the list of one hundred are thorough advertisers—these are the resort cities. These cities have an average increase of 72.7 per cent. and they include Long Beach, California (with an increase of 212.2 per cent.), Jacksonville, Florida (increase of 58.7 per cent.), Asheville, North Carolina (increase of 51.9 per cent.), Pasadena, California (increase of 49.7 per cent.), and Miami, Florida (increase of 35.1 per cent.). These increases are more nearly normal growths for this type of city than is the case of any of the previous groups, and these increases have been maintained in resort cities over a number of years. There are so many resorts of various kinds in the United States and all of them are such prolific advertisers that there arises the question why only seven have registered a large increase in population. In an analysis of the resorts of this group, there appears to be in all cases a combination of resort and business which makes the attraction; and this combination, being somewhat different in each case of the seven, places these cities in another group of sporadic types with a common factor in resorts.

The majority of resorts advertise for a transient trade, and thus they do not appear in the category of cities with permanent increases. This is shown by Atlantic City, New Jersey, which increased by about 10 per cent. only in the decade; but this 10 per cent. probably means a great increase in the number of visitors

to the resort, since the 10 per cent. represents the number of additional persons, permanents, that are needed to care for the transients.

F—Other Cities: This accounts for fifty-six of the hundred cities of greatest increases in population. Of the forty-four remaining, there are ten cotton and cotton products cities, nine food products cities, eight lumber and lumber products cities, and seventeen scattered cases. A small percentage of these advertise extensively. The most noteworthy cases are Phoenix, Arizona (with an increase of 160.9 per cent.), San Diego, California (increase of 89.4 per cent.), and Los Angeles, California (increase of 80.7 per cent.). Without going further in an analysis of these city groups, there is enough evidence to make the assertion that the majority of cities of maximum growth during the last ten-year period did not attain their numbers through any consistent internal organized advertising. They were the product of the times, pure and simple.

City Advertising

Advertising has in so many instances been the result of mimicry and imitation that there is a possibility of classifying into types much of the advertising now being indulged in by cities. The number of cases where the city has departed from certain established types of advertising is not many. The tendency to do this is more marked to-day than ever before. It is strange that in these days when business is being tried for efficiency the time-worn schemes of city advertising have never been investigated. Some of these cost little or no money, and it is probably for this reason that no great concern has been felt for them. Three very common types are mentioned here

A—The City Slogan: The most widespread feature of city advertising, appearing more commonly than any other one type, is the city slogan. These phrases, which are intended as catch-words, are in 95 per cent. of the cases valuable only as an indication of the city fathers' aspirations for their child. In a large number of instances they encompass so much as to make them specifically unattainable; and in most cases they degenerate into platitudes that border upon utter foolishness. As a rule they are commonplace and ineffective because of these reasons

"The City with a Personality"—Tulsa, Oklahoma

"Where to-day's dream is to-morrow's opportunity"—Wichita Falls, Texas

"The City of Opportunity"—Gary, Indiana

"The City of Diversified Interests"—Canton, Ohio

"Where enterprise was invented"—Lansing, Michigan

"The Place with the Power and the Push"—Columbus, Georgia.

The following statment appeared in a recent number of the Providence *Journal:*

> The Lions Club, an organization in Wilmington, Delaware, offered a prize of fifty dollars not long ago for the best local "slogan." The announcement is now made that two young men of the city both entered the winning phrase in competition, and so presumably the prize was divided between them.
>
> Their choice is interesting: "Wilmington—the first city of the first state." It might be thought that while there is no doubt of Wilmington's municipal primacy in Delaware, as the next largest community has a population of only five thousand, the reference to "the first state" is a mere baseless boast . . . .

Now and then a slogan is invented that sticks to a city and becomes, even in boastful language, a constituent part of the city's advertising. In general, however, this rule may be applied, namely, that it is not so much what a city decided to say of itself that counts in this matter but what it can induce outsiders to say of it. The test then of a successful slogan is its adoption without, not within, the confines of a city, and to this test very few slogans measure.

B—The Trade Circle: A second type of advertising indulged in by cities is a map showing the trading district. Frequently this is printed by drawing around the city a circle of varying radii—80, 100 or 125 miles, and the inference is assumed that the population within the area has trade connections with the center. In most cases this is vicious advertising.

Wichita Falls, Texas, publishes such a circle with a hundred mile radius showing the railroad lines converging toward that city, and the map is labelled "Wichita Falls Trade Territory." Wichita Falls has a population of 40,000; the 100-mile circle just misses Fort Worth, population of 106,482, on the southeast; Oklahoma City, population of 91,295, on the northeast; and is within fifteen miles of Dallas, population of 158,976. This is the common fault of such types of advertising; and in every case examined there has been neglected the influence of adjacent areas, with a trade in most cases of greater importance, the possibilities of transportation, and the normal flow of trade.

The *Providence Magazine*, Rhode Island, published by the Chamber of Commerce of that city, publishes in every issue of the magazine a map of the northeastern section of the United States. Around Providence, New York and Philadelphia are drawn circles with radii of 80 miles. The Providence area is marked "Third most populous 80 miles radius in the western hemisphere; population 4,188,651;" and the order of importance of these areas is given thus: New York, Philadelphia, Providence, Boston, Chicago

and Baltimore. The 80-mile radius around Providence encompasses Middletown, Waterbury and Hartford, in Connecticut; Springfield, Holyoke, Lowell, Lynn, Salem, Gloucester and Lawrence in Massachusetts; and Nashua in New Hampshire—and not one of these cities is connected directly with Providence. As a matter of fact any one of twenty-five cities lying between Trenton, New Jersey, and New Haven, Connecticut, would with an 80-mile radius surround a population larger than that given for Providence. It is, however, not so much a question of veracity concerning figures with which we have to deal, but an inference concerning trade movements, and in this particular the Providence "Trade Circle" is highly mendacious.

C—The Bill Board: A third type of advertising indulged in by cities is the bill board, located at some favorable site along the automobile highway or railroad. In general this is more modest advertising than either of the other two types, and it has the advantage of gaining a larger audience than the others. No estimate of the value of these can be made from any records or impressions which city organizations have on file. A rather widespread lack of knowledge concerning them was apparent. Obviously many of them have outlived their usefulness, as the data on them are obsolete; while the general state of unrepair of some of them rather indicates that they are not rated high in those communities.

Advertising may be competitive or it may be informational; advertising of a competitive nature is not economically justified; it has a selfish aim and it is a burden to the ultimate consumer. Advertising of an informative character is in the line of education, and the consumer is willing to pay for this. Most city advertising is too competitive to be ranked high in advertising science. The location of manufacturing concerns is determined by many factors, the least of which during the last decade, at least so far as large establishments are concerned, appears to have been the embellished advertising of the various cities. Cities which are large advertisers have not always increased as much as the average increase of urban communities in the United States (28 per cent.) for the ten-year period. Denver (20.2 per cent.), Portland, Maine (18.3 per cent.), Portland, Oregon (24.6 per cent.), San Francisco (21.5 per cent.), all fell short. Seattle, one of the most consistent advertisers and incidentally an advertiser on rather a higher plane than is usual, has increased but little more than the average city increase for the entire United States (33 per cent). It should be noted, however, that this city's widespread advertising campaign is of too recent date to be effectively measured in the returns of the last census.

City growth in any country should have a normal progress. It should avoid the utter despair and degeneracy portrayed by Wells in his "citylessness" Europe, but also it should avoid the profligacy of "citymoreness."

In a new country where the physical advantages for development are eminent, but there is lacking a certain density of population, it is a legitimate process to attract settlers by rebating transportation rates; by offering free lands and implements and by establishing a preferential tax rate; but in a land so overburdened with cities as the United States is threatening to be, there is something inconsistent between the struggle of cities to increase by large percentages and the ideal of the land as a self-sustaining nation.

It has been said that the statement that people are leaving the country more and more is to put a misleading emphasis on a normal fact in the modern growth of population. It is further explained that the city increase is the normal result of country growth, that country populations should be thinner than city populations, and that cities should take the larger part of the natural increase of the country populations; this is the explanation of what is happening. Notwithstanding, the percentage of urban dwellers has constantly increased, from 35.4 per cent. in 1890, 40 per cent. in 1900, 45.8 per cent. in 1910 to 51.4 per cent. in 1920. Just what the right ratio between urban and rural communities should be is problematical, but there appears to be considerable concern over the fact that in 1920 for the first time the percentage of urban population passed the half-way mark of the total population. The increase of urban population from 1910 to 1920 was 28 per cent.; and of rural 3 per cent. On the other hand the beginnings of stress for food indicate that the 3 per cent. are not adequate to care for the increase of 28 per cent.: or that 48.6 per cent. rural population is hardly a sufficient number to give the country a surplus. While the numbers of rural dwellers increased, the number of workers in rural communities actually decreased by something like 100,000 and this with 14,000,000 more mouths to feed. City advertising must take account of this fact in the near future. Is it safe to attract from rural communities? Is it a legitimate aim in city advertising to outclass in numbers some other rival community? What is the function of such advertising? No community has attempted to answer this, but until some vision of these things is before the advertiser, city advertising will be wasteful and inefficient.

METHUSELAH OF THE MISSISSIPPI

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THE Father of Waters, with all its mysteries, presents no individual prototype of Methuselah, but it harbors in its bosom a species of fish that is even more ancient with reference to other kinds of fish than was Methuselah with reference to his youngest grandchild of the *n*th generation. The paddlefish, often called spoon-bill cat (sometimes, I dare to say, termed *Polyodon spathula*), is our single representative of an order of shark-mouthed fishes which is believed to date back to a very early period in the evolution of the finny tribes of fresh waters and the sea. There is one other living representative of the order, but it is found only in some rivers of China, being dignified with the scientific name of *Psephurus gladius;* the popular Chinese name we have forgotten, if we ever knew. Some seventy-five million years ago America boasted another representative of the family of Polyodontidæ, but we know it now only through the fossils found in eocene formations in Wyoming;—and not many of us know it even there! The two lone survivors of an ancient family, Polyodon and Psephurus, are far removed from each other and presumably have not had even a speaking acquaintance within a million years.

The paddlefish might be a good deal more lonesome if it did not have a few near contemporaries dwelling alongside. Closely associated with our hero in the society of oldest inhabitants of fresh waters are the sturgeon, gar-pike and bowfin. Could we steal in upon a clandestine meeting of that dignified society it would be interesting to compare the distinguished members. Observe first the paddlefish with its mostly naked skin and (using an x-ray machine) its cartilaginous (not bony) skeleton. There, too, are the sturgeons who also have a cartilaginous skeleton, but they wear a knightly armor of hard bony plates or scutes; besides they boast a magnificent "beard" of four barbels—a mustache it might better be called, since the barbels are in front of the mouth—while the paddlefish has only the feeble adornment of two barbels and these so small that it takes an expert to find them. Next come the wicked old garpikes—to say nothing of two strange fishes of Africa which have been condemned without a hearing to be called Polypterus

and Calamichthys. These wear an even more complete coat of mail than do the sturgeons, but their skeleton is somewhat new-fashioned in respect of being largely bone. Finally we see the bowfin, grindle, dogfish, mudfish, lawyer—or whatever you choose to call him; he, too, has a bony skeleton, and, while not strongly mailed, is covered with scales. He might be thought to be almost modern, except for—but that's another story which has nothing to do with the paddlefish. It is noteworthy that three of the groups of the ancients—the sturgeons and garpikes, as well as the paddlefish—have either prolonged snouts or bills, while all the regular every-day sort of fish are almost invariably short-nosed, as everybody knows.

Lest it be thought that in singling out the paddlefish as a representative of antiquity we do an injustice to the sturgeon, let it be said now that, conceding to the "hackle-back" all the honor due to abundant years, we can not venerate him as we do the paddlefish. Jared attained an age but a year or two less than Methuselah; but does he rival Methuselah in our esteem? By the unanimous verdict of succeeding generations, Jared's name is confined in the archives of history, while that of Methuselah remains a household word, as familiar as those of George Washington or of Abraham Lincoln. How, then, could the sturgeon dispute the proud place of Polyodon in the halls of fish fame?

What are the more striking external features of the paddlefish? Behind the long spatulate bill we observe a very wide mouth, sharklike in position, being entirely on the under side of the body, but relatively as cavernous as that of a hippopotamus; there are spiracles open above, as in sharks; there are no spines in the broad shoulder fins; the body is scaleless, except for isolated vestigial scales embedded in the soft skin and a continuous series of small rhombic plates on the upper part of the tail; and the tail, by the way, is heterocercal. This last named feature is important. Do not forget the heterocercal tail! Heterocercal, it may be explained, is merely a hard name for the kind of tail which we associate with sharks, that is, one with the vertebral column extending into its upper part, giving a rakish, saucy effect. But the snout, after all, is the principal thing, being one third of the total length in fish of small size and about one fourth of the total length in large fish 5 or 6 feet long. It is rigid in the middle line, but has thinner and more flexible margins. As we shall see, it is so covered with sense organs and full of nerves that it must be capable of serving most delicate tactile functions.

Another external feature of the paddlefish, which is very sug-

gestive of the sharks and their relatives, is the color contrast between the upper and lower sides. The back and the upper parts of sides have steel or slate-like hue, while the underparts are glistening milk white. The fins of the most mature individuals may be slate-like or dashed with a delicate tinge of salmon pink. A peculiar reddish tint has sometimes been observed over the bodies of fish that have recently spawned.

About 6 feet would appear to be the maximum length attained by our species, though its Chinese relative is said to attain a length of 20 feet. Paddlefish taken in the Mississippi and its tributaries are usually between 2 and 4 feet long. The largest known example, weighing 163 pounds, was taken in Lake Manitu, Ind.

Barring exceptional records, the paddlefish has been found only in the Mississippi River and its principal tributaries. It is rarely found in lakes or rivers of a depth less than 10 feet, and may, therefore, be quite unknown to persons living a short distance from one of the principal rivers of the Mississippi Basin. Thus, when an individual example was caught a few years ago in the Des Moines River near Ottumwa, it astonished the local fishermen who had seen nothing like it before although they lived but 70 miles from the Mississippi River where paddlefish were as well known as catfish. Strange to say in this connection, one of the largest paddlefish of record was taken as far inland as Lake Chautauqua, N. Y., in 1890, the fish having a length of 6 ft. 2 in., a girth of 4 ft. and a weight of 123½ pounds.

Rare as it may be in the smaller tributaries, the paddlefish has real commercial importance and wide distribution in the larger streams of the Mississippi Basin and in neighboring deep lakes connected with the river. In Lake Washington, Miss., as many as 150 barrels of Polyodon have been taken in one haul of a seine two miles in length, while, a thousand miles to the north, in Lake Pepin, an expansion of the Mississippi between Minnesota and Wisconsin, it was (until very recently) possible for the big seine to bring in a thousand or fifteen hundred pounds of paddlefish in a single haul.

In several southern lakes, paddlefish and other species are taken with a great seine, from one to two miles long and from 15 to 30 feet deep. The seine is wound on a large reel carried on a heavy barge, which is towed around a circular area, a mile or more in circumference, while the seine is reeled out. The barge being then anchored, the crew of a dozen men wind in the seine by walking up the spokes of the wheels at each end of the reel, as on a ladder, so that the reel is made to revolve. As the seine is thus gradually rewound on the reel, the fish in the circle enclosed by the portion

Photo by R. E. Coker.

ONE THOUSAND POUNDS OF PADDLEFISH, BUFFALO FISH AND CARP. LAKE PEPIN, 1913

of the seine in the water become confined to a narrower and narrower space, while they dart wildly about seeking means of escape. It takes about 4 hours to complete the operation, which may bring in a hundred valuable paddlefish.

In Lake Pepin, the seine, which is nearly a mile in length, is hauled ashore by long lines passed over stationary winches located on the banks and turned by gas-engine power. While in northern waters the paddlefish has no well-developed roe to enter into the commercial appraisal of the fish, nevertheless it has, for some years, been accounted one of the most valuable species to catch on account of the value of its meat. The result of the intensive fisheries practiced in various parts of the country has been, of course, to bring about a rapid depletion of the supply of this fish.

As regards the larger rivers, seines can be employed only along the shores and in outlying waters; where current prevails, the fishermen resort to the use of fyke nets (hoop nets) or of trammel nets. At Keokuk, Iowa, fishermen were observed to take paddlefish by the use of trammel nets set at night in the very swift water below the dam. Here the operations were attended with some little danger, since the greatest care was required to prevent the extremely swift current from throwing the boat against old piles and other partly or entirely submerged relics of the time of construction of the great dam.

I recall vividly my own experience in a small boat fishing close up in the tail race below the power house of the Mississippi River Power Co. The hours were wee and small, for we had gone out at 12 midnight in accordance with the dictum of the few fishermen that cared for that particular kind of fishing. The waters, which had fallen 30 feet through 13 big turbines and shot out through the submerged chambers of the power house into the tail race paralleling the house, flowed down stream with great force and turbulence. At the same time, the surface water rolled outward through the remnant of an old cofferdam, represented by scattered piling, some partly exposed and some altogether submerged. The night was calm elsewhere, but not so here. In the rushing, swirling, waters, the management of the boat alone might have seemed a sufficient task; but, with the drag of a long trammel net being paid out over the stern, when the conflicting currents often chose to take the net one way and the boat another, the energies and resources of the fishermen were severely taxed. Piles looming suddenly in the darkness, boiling, slopping waters everywhere, suspicious swirls fixed in location and indicating submerged dangers, excited commands to the oarsman and from the oarsman—all combined to make the experience one of thrills more delightful in the retrospect than in the actuality. Alert eyes, quick action, and strenuous exertion, not to mention good "sea-legs" and "seamanship," saved the day, or rather saved the night, during the paying out of the trammel. If the trammel net was not entangled with the piling, its taking in and the removal of the paddlefish was relatively simple when the boat had drifted well below the zone of danger. But the drifting was not always unchecked; the net might become entangled on a pile in the strong current—and then there was some joy in life while extricating as much of the net as the piling chose to release. For well-considered reasons, I did not personally pursue the fishing operations throughout the period of fishery—several hours. However, after a brief experience, I had learned something of the midnight habits of the paddlefish in this region, and I came to suspect that the broken-snout paddlefish, which were so frequently encountered in the waters below the dam, were not unacquainted with the piling. If, in that rushing current, these seemingly stupid and dim-visioned fish thrust their long snouts between two piles with the same bravado that they rushed into the trammel net, I think I know what would happen.

What happens to the paddlefish after it is captured is less exciting. In dressing the paddlefish the heads and fins may be dis-

Photo by A. D. Howard.

A CATCH OF PADDLEFISH AT HYAMS CUT, OFF HYAMS, LA.

carded or saved and boiled for the oil they yield. The roe, which weighs from two to fifteen pounds in a single fish, is put on a coarse wire sieve and rubbed by hand across the wires until the eggs are separated from their membranes and drop into a bucket beneath. The eggs in this form, or caviar, when mixed with special salt, are ready for shipment, although they must undergo still further preparation before they are ready for the table.

Commercially the paddlefish is highly esteemed by fishermen. The flesh is good and, though it has not become known under its own name, it is shipped to the larger markets there to be dried, smoked, and masqueraded as "dried sturgeon" or as "boneless cat." In Lake Pepin in 1913 they would not even call a paddlefish in the seine by its proper name or by its colloquial designations of "spoonbill cat." They patly designated it *shovel-nose sturgeon* and shipped it to Chicago where, at a time of low prices for fish, it brought 12½ cents per pound while buffalofish and carp brought only 3½ cents.

The roe is much more valuable than the meat, since it is used, like sturgeon roe, to make caviar. While, strictly speaking, caviar is the roe of the sturgeon of Europe or America, prepared in a certain way, nevertheless *erzatz* caviar is made from the eggs of

several species of fish, including the whitefish of the Great Lakes. Under regulations formulated to enforce the Pure Food and Drug Act, other caviar than that made from sturgeon roe must be designated when sold, by the name of the fish from which it is made, as "whitefish caviar." The roe of the paddlefish is, however, so nearly like that of the sturgeon that paddlefish caviar, it would seem, is hardly to be designated as an imitation. In 1917, at Keokuk, Iowa, sturgeon roe was bringing $2.95 per pound and the meat 16 cents per pound. Paddlefish roe probably brought approximately the same price, and, as the roe of a large paddlefish may weigh 15 pounds or more, it is evident that an individual fish in proper condition represents a very valuable catch.

But how long will it last? In 1894 the paddlefish was not esteemed; but the catch in the Mississippi River and some of its tributaries amounted to more than 1,000,000 pounds, valued at about $21,000. It was about 1896, apparently, that fishermen along the lower part of the Mississippi River began to utilize the roe for making caviar, and in 1899 the catch had increased to 2,473,000 pounds, valued at $55,514. The rated value is proof that the fish was little appreciated; nevertheless its early decline in abundance is evidenced by the fact that the catch of paddlefish reported by the Bureau of the Census for 1908 amounted to one and one half million pounds, valued at $49,000: the unit value was going up some. Later the fish began to bring a price, but we have no recent general statistics to show the present trend.

The decline of the paddlefish in Lake Pepin is notable. In 1903 and 1904 it was one of the most abundant fish in the lake throughout the summer. Big catches were regularly made. Subsequent statistical canvasses conducted by the U. S. Bureau of Fisheries showed a catch of hardly 9,000 pounds in 1914 and less than 3,000 pounds in 1917. Visiting the lake in September, 1921, I was told that the first paddlefish of the season, 4 in all, had been taken the preceding day. I witnessed a catch of 20 examples, 30 inches to 4 feet long, which were greeted with enthusiasm by the fisherman as representing a big find. In 1913, I had observed a larger haul which was regarded as in the order of the day. The barrier across the river at Keokuk has perhaps had something to do with the rapid disappearance of the paddlefish from Lake Pepin relatively to its general decline in all waters.

II

The paddlefish is remarkable not only for its bizarre appearance, its primitive structure, and its isolation from any relatives,

but also for its feeding habits. One might suppose that a species which had survived for such a long period would be found to be peculiarly fitted to take care of itself in conflict with associated species; that like the sharks of the sea and the garpikes and bowfin of fresh waters, it would be extremely predaceous, if not actually pugnacious; but, like Methuselah in his last years, or last centuries, perhaps,—the paddlefish is extremely peaceful in disposition and addicted to a diet of the simplest character. It may have attained its second childhood, or it may never have left its first childhood, as regards the matter of feeding. The young of all of our common fishes, having tiny mouths, must feed upon the smallest food articles. They are practically all, therefore, "plankton feeders" in early infancy; that is to say, they consume the minute floating plants and animals or organic materials which comprise what is called plankton. As a general rule plankton is to infantile fish what the bottle is to infantile man. Whether or not Methuselah found it necessary to revert to the bottle after attaining an age of seven or eight hundred years, we find the paddlefish of all sizes and ages subsisting upon the sort of food which a black bass would be ashamed to be caught eating at an age of six or seven months.

"The most remarkable in many ways of our American freshwater fishes," say Professor S. A. Forbes, a veteran student of the fishes of interior waters, "is the Polyodon or paddlefish, and in nothing is it more peculiar than in the fact that, although it is one of our largest fishes, reaching a maximum length of six feet and a weight of a hundred and sixty pounds, it is essentially a plankton-eater, feeding largely, and sometimes almost wholly, on the smallest aquatic animals and plants for the appropriation of which it has, in its gill-rakers, a straining apparatus scarcely less effective than that of the whalebone whale. To strain out the plankton, it holds its enormous but weak-jawed mouth wide open as it swims about, permitting the water to flow through its very wide gill slits, getting thus not only the smallest animals and plants, but many insect larvæ also of kinds abundant on the open bottom in comparatively shallow water. It is indeed a living, fine-meshed, water-net."

It is said that one may often scrape more than a double handful of Entomostraca (small water "bugs") from the mouth of a paddlefish freshly brought up by the seine.

Scientists, as well as others, sometimes have a special fondness for proving the fitness of things, or establishing a positive relation between structure and function. Some have thought that the paddle of the paddlefish was used as a sort of shovel to stir up the mud on the bottom ahead of the fish, after which the gill apparatus

Photo by A. D. Howard.

PART OF CATCH OF PADDLEFISH, HYAMS CUT, OFF HYAMS, LA.

would effect a separation of the nutritive organic matter from the mud. It does not appear that it would be physically practicable for the straining apparatus to accomplish this result, inasmuch as the mud would be composed of as fine particles as the food matter. It is also a reasonable presumption that, if the paddle were used in this way, its edges would be found considerably abraded from frequent rubbing against mud and débris on the bottom.

If the paddlefish fed habitually by stirring up the sediment upon the bottom we might expect to find an appreciable quantity of silt in the stomach contents; but observers say this is not the case. The content of the stomach of the paddlefish is usually, indeed, a very clean collection of the minute animals or plants such as occur swimming or floating in the water more abundantly than amidst the bottom materials.

It is much more likely that the paddle is a tactile organ serving to guide the fish into areas of water where its normal food is found in the greatest abundance. Feeding as it does upon very small particles of floating food, the paddlefish would seem to require a sort of antenna by which to feel its way into the thickest swarms of food, and the long flat paddle, which is "fairly paved

with sense organs," seems well adapted to serve the function of a "feeler." One observer found occasional examples of paddlefish gorged with larvæ of mayflies, those interesting insects which spend a year or two of immaturity on the bottom of a river to emerge finally for but a single day or two of glorious aviation; but in every such case recorded, the adult mayflies appeared in vast numbers in the evening of the same day. It may, therefore, be presumed that the paddlefish merely captured the larvæ in their journey from the bottom to the surface of the water preparatory to the emergence which would so closely precede the end of the journey of life. Some have recently been found gorged with aquatic insect larvæ of the only species that roams freely in the water making its base neither at the bottom nor at the surface (Corethra).

Perhaps one ground for the old supposition that paddlefish feed upon the bottom is the fact that they are rarely found except where the water is deep, and the bottom in such places in interior waters is usually muddy; but on the other hand, it is observed that those taken in seining operations, when they become gilled in the seine, are always found near the cork line. As a matter of fact, the paddlefish is probably nocturnal in its feeding habits, and retires to the darkness of the deeper water during the day, not for feeding, but for protection and repose. We have previously referred to the fact that operations with trammel nets at Keokuk, Iowa, were conducted at the surface at night. The eyesight of the paddlefish is very deficient and, as it leads a life that is by no means sedentary, it must have some other acute sense organs for its guidance, and this apparently is the function of the paddle.

Concerning the extent and seasons of its migrations we have virtually no information. It is known that it roves about the lakes in schools and that it disappears from observation for brief periods, but there is lacking evidence that it entirely leaves any locality in which it is commonly found at some season.

It is remarkable, indeed, that this fish should have maintained itself through countless years, in competition not only with other species of like size and more "suvigrous" disposition but also with the smaller fish of nearly all species, which take the same sort of food, and its survival is all the more an occasion for wonder since it is apparently gifted neither with keen vision nor with such a measure of intellectual activity as we could term "good fish sense." Observe its behavior in a tank; it repeatedly swims against the ends or sides of the tank, as if it could not see beyond the end of its

nose. When, in the open water, the fish strikes a net it often stops, pushes weakly forward a time or two and then gives up, turning on its back and floating along the cork line. It allows itself to be removed by hand almost without a struggle. Dr. Hussakof, formerly of the American Museum of Natural History, has well described its behavior under such circumstances:

"Its sense of sight is poorly developed, as indeed one might infer from its small, beady, black eyes. If its 'nose' is caught in the seine it makes only feeble efforts to free itself, and usually fails in doing so. The contrast between the clumsiness of the spoonbill and the alertness of an active fish is strikingly brought out if a garpike is taken in the same haul; for the gar makes tremendous efforts to escape and, unless rendered unconscious by a blow with a mallet, will flash through the seine as if it were gauze. Leaning over the side of the boat, near the corkline of the seine, one may seize a five-foot paddlefish by the 'nose' or the tail and haul it into the boat; the only resistance is that of weight. The fish has absolutely no sport value."

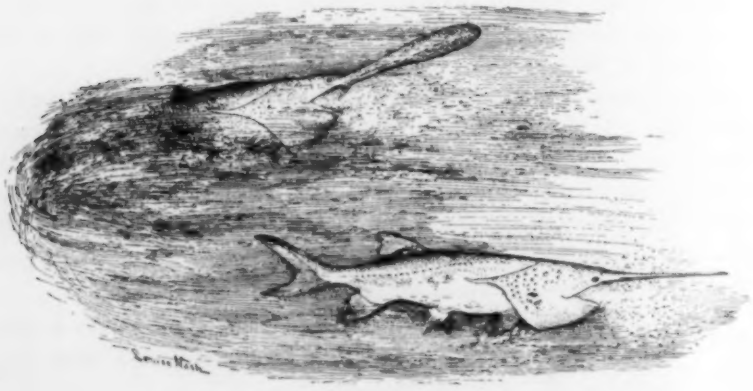
As resistant as the paddlefish may be to the changes of time and the physical injuries acquired in the open water, it does not stand handling or close confinement. Attempts to convey paddlefish in a boat on the Mississippi River, in a large stock watering tank which was carefully tended while traveling a distance of about 100 miles, usually met with failure. Few paddlefish survived the period of eight or ten hours consumed by the journey. Attempts to retain them in wire-meshed enclosures 20 feet square in lakes which were their natural habitats have also failed, though the fish have been successfully kept by fencing off a small arm of a bayou. On one occasion some paddlefish were successfully transferred in a fish car from the Mississippi River to the Portland, Oregon, exposition. They lived during the journey but all died during a brief delay in the yards before the fish could be delivered to the aquarium of the exposition.

After many trials a considerable number of paddlefish, mostly of smaller sizes, were placed in a reservoir at the U. S. Fisheries Biological Station at Fairport, Iowa. The reservoir is just a little less than an acre in surface area and about 16 ft. deep. Here the paddlefish have apparently found conditions to their purpose, for nearly all of them have lived for about 5 years and gained considerably in length.

There was observed a peculiarity in the behavior of the paddlefish in a tank in that they soon turned upside down, when they

would remain motionless and appear to be dying. If they were righted with the hand, they would then swim about as if entirely revived, but after a time would turn over again. Why? This is not the only puzzle of the paddlefish. In one experiment some fish were conveyed successfully after tying a cork on the top of the snout in such a way as to compel the fish to remain right side up. An investigator, by the way, found that a paddlefish tethered to an empty gallon jug by a line 5 or 6 feet long and set free in a lake could be kept in good condition and recovered at will. The seeming contentment when moored to a jug would seem almost human but for the fact that the jug is reported to have been empty.

The paddlefish may not be gifted with intelligence of a high order, but at least it can keep a great secret; that is, as to when, where and how it breeds. We know the eggs, for the large roe with eggs sometimes seemingly almost ripe, is a staple article of commerce, but where and when the eggs are laid, if they are laid, and how they are cared for, if they are cared for, and where and how the new-born young live and grow—the fishermen and the scientists, in spite of repeated investigations, are still guessing. On only one occasion have examples less than 6 inches in length been taken, and these were gathered by an indefatigable searcher who seined the bars of the Mississippi and Ohio Rivers and neighboring sloughs and lakes in the vicinity of Cairo, Ill., throughout the period of an entire year. Where are the developing eggs and where are the new-born and the infants less than 4 inches in length? This is Methuselah's great secret. Problems seemingly much more difficult than the spawning of the paddlefish have been solved with less effort—but the paddlefish still cherishes its own mystery. If you



wish an easy task, find out where Capt. Kidd buried his treasures or where the paddlefish hides its young.

This much, at least, the paddlefish lets us know: that there are no evident external differences between males and females; that paddlefish of some 15 pounds weight may be apparently sexually mature; that the roe of a large fish may weigh as much as 16 pounds (10 pounds being more nearly an average yield); that the dark brown or blackish eggs are much like those of the sturgeon in size and color, being slightly oval in form, with diameter of 1/10 of an inch more or less.

Regarding the rate of growth of paddlefish in nature we know nothing, but some observations have been made upon the growth of those placed in the storage reservoir of the Fisheries Biological Station at Fairport, Iowa, in August and September, 1916. The average gain in length of 26 specimens after a period of a little more than 2 years was at least 12 inches, and possible more. No doubt the conditions of growth here were not as favorable as in the free range of the river and larger lakes.

Of course, the paddlefish must have enemies; anything else would be too good to be true. Unless the young are as successfully concealed from predatory fish as they have been from man, or unless they are for some reason distasteful, they must be frequently devoured by predaceous fishes of their environments, such as the pike, bass, garpike, bowfin and catfish. The great number of eggs formed by each large female suggests that there is a heavy mortality somewhere in the life history of the fish which must be compensated for by heavy production. The only enemy of the larger paddlefish that has attracted special attention is the lamprey, or "lamper eel," which seems to regard the paddlefish as its special prey, perhaps because over nearly the entire surface of its body the paddlefish lack a protective armor. From 10 to 25 lampreys may sometimes be found upon an individual paddlefish, and they even invade the mouth. The marked habit of the fish of leaping from the surface of the water has been explained as a means of throwing off the lampreys.

Whatever enemies the paddlefish may have encountered in all the ages of the existence of the tribe, it has successfully survived in spite of them, until within comparatively recent years it has encountered that most interesting and dangerous of all adversaries,—that which drove the buffalo from the plains and the passenger pigeons from the air, that which destroys the forests out of which it constructs its lodging places, that featherless, scaleless, two-

legged animal known as man. A story might be written upon his habits; how he has displayed marvelous energy in industrial occupation; how he has perfected what are called fine arts, attained great skill in so-called liberal arts, and developed complex systems of thought known as the sciences; how he has mastered his larger enemies and how he still pluckily battles against the smallest and most intrepid of his foes; how, according to the promise, all things are being brought under his feet and he is acquiring dominion over the works of the fingers of the Almighty and *how he exercises that dominion!*

This would bring us to a chapter of the story of man that would not be without its sadder features. We would learn that, while he has advanced in a form of development known as civilization, he seems to have manifested certain signs of degeneration. It would appear that, in the pre-civilization stages of development, he destroyed that which threatened to destroy him, or that which he could profitably use, but that, when he became highly civilized, he became more or less blinded with the glory of successful battle and destroyed not only his enemies but those things, whether trees, four-footed animals, winged or finned creatures, upon which he depended in part, for food, raiment or shelter. If this story went into detail it could not avoid mention of the paddlefish and what the combined hero and villain of the story did to it. How many millions of years did the paddlefish withstand the changes of time while glaciers came and went, continents sank beneath the sea, and mountains rose from the deep? The laborings of the earth may at times have destroyed great quantities of paddlefish, but to the species as a whole these were trivial events. How many thousands of years did the uncivilized tribes of man fish in the water of the Mississippi and its tributaries? This was of slight significance to the ancient species. But at last something happened to the old piscine Methuselah of far greater importance than all that had gone before. Civilized man appeared upon the banks of the great river and in less than 100 years brought the paddlefish almost within sight of extinction. To judge from present indications another fifty years will bring the end, when *Polyodon spathula* will have joined the "great majority" of extinct species. And yet there is hope; for man is showing signs of an awakening, or of an atavistic return to the conditions in which he regarded useful prey as something not to be briefly enjoyed but to be conserved for all time.

But, taking things as they stand, could we blame a thoughtful

paddlefish if, after due deliberation upon its experiences with this new enemy, it should thrust its long snout above the surface of the water and cry out in anguish: "Better a thousand cycles of Cathay than 50 years of modern man!"

THE PROGRESS OF SCIENCE

CURRENT COMMENT

By Dr. Edwin E. Slosson
Science Service

THE BODY GUARD

That mankind has not given up hope of an "elixir of life," in spite of the disappointments of a thousand years or more, was shown by the headlines of the papers on November 15 after Dr. Alexis Carrel had read a paper before the National Academy of Sciences at the Rockefeller Institute on "Leucocytic Secretions." The title was not engaging, but everybody knew that whatever Dr. Carrel said would be worth hearing, and when he told of the way certain fluids from the white blood corpuscles revivified dormant cells and promoted the growth of the tissues of the body, some reporters jumped at the conclusion that the fountain of immortal youth was at last in sight. Dr. Carrel was far from making any such rash promises, but he did report a very interesting extension of our knowledge of the restorative processes of the body from which we may fairly expect in time some beneficial applications.

Dr. Carrel has been able to carry on the study of such processes farther than before because he found a way of working with living cells outside the body. Ten years ago he picked out a tiny bit of the heart of an unhatched chicken and has kept it alive on glass in a warm place ever since by feeding it with suitable nutritive solutions and washing away the waste products. Now the chicken, if it had been allowed to hatch, would probably have died five years ago, but this particular bit of its heart muscle, having been better cared for by Dr. Carrel than it could have been by the chicken, is not only alive, living and growing, but seems as young as ever and there is no apparent reason why it should not continue on indefinitely, although the matter that composes it has changed more than a thousand times. Dr. Carrel has also found that the white cells of the blood can likewise be worked with outside the body. They can be cultivated on mica plates like colonies of bacteria and their influence on other cells studied at will in the laboratory. This indeed is not so surprising as his previous cultivation of a piece of muscle for these white blood cells lead a somewhat independent life even while they are in the body.

Any one who has looked at blood through a microscope will have noticed that there are two kinds of bodies floating in the fluid. There are first rolls of little round red disks looking like checker men. They carry around in a mechanical sort of way the oxygen received from the air in the lungs. But mingled with them in the blood stream are a few bodies of a different and more active sort. They are colorless and larger than the red corpuscles and have no definite shape, but adapt themselves to their situation, crawling through crevices in the capillaries and wandering about freely among the tissues. Instead of being limited as to legs and arms as we are they stick out any kind of a limb anywhere they may happen to need it at the moment like the simplest of independent animals, the amœba.

The great Russian physician, Metchnikoff, discovered that these white blood corpuscles—or leucocytes, to give them their Greek name—served a useful purpose in eating

up the microbes that invade our bodily citadel. In case of a wound they rush to the spot in increasing numbers and pile up their bodies in the breach of the skin wall. Every leucocyte is as heroic as Arnold von Winkelried. Wherever there is infection there these defenders may be found fighting the foe and perishing by the thousand in the attempt.

But now Dr. Carrel has found that they do much more than attack disease germs. They also in some way stimulate the structural cells of the body to greater exertions and promote the reconstruction of damaged tissue. They aid in the healing of wounds and the rebuilding of bones. They secrete an activating substance of some sort that revives the energies of cells that have grown tired or old. In short they act not only as a patrol force to discover and combat microbic enemies but they further see to it that the other cells do their duty. No wonder that physicians have found that an examination of the blood to determine the number and activity of the leucocytes is one of the best ways of finding out what chance a patient has of overcoming his disease.

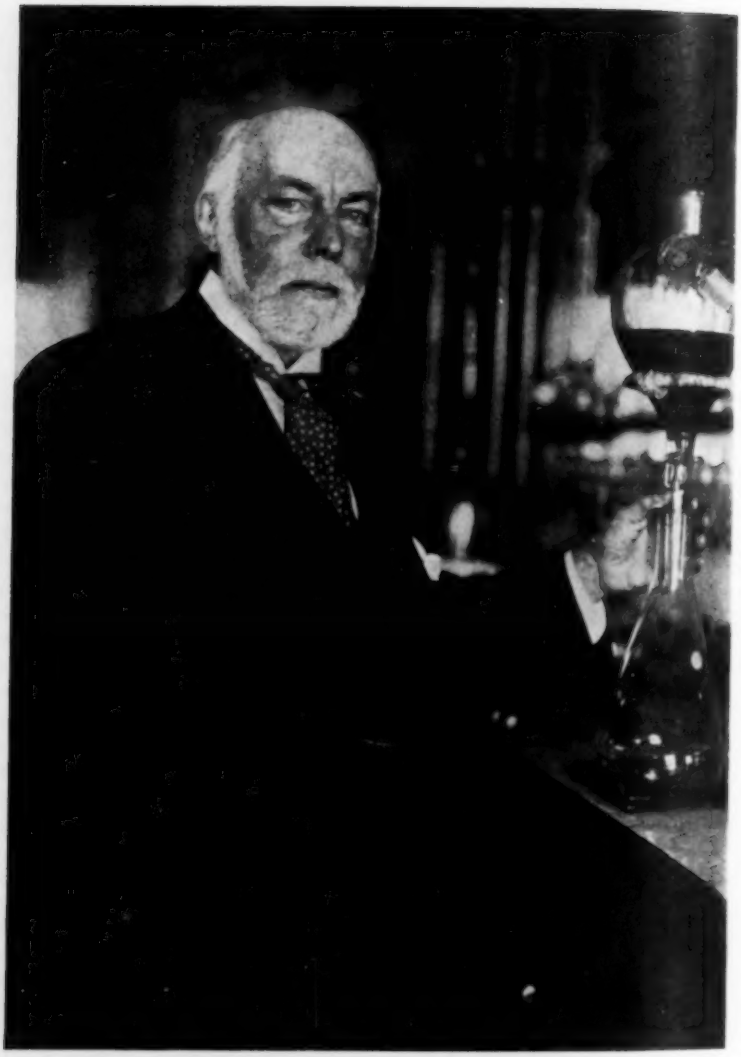
TO EXCHANGE: A CHEMICAL FOR A COLONY

THE German chemists are trying to win back the colonies that the German Kaiser lost. They are offering to trade a new coal-tar drug for the African territory which Germany held before 1914, but which fell to the victors of the Great War. This territory amounts to a million square miles, or one third the area of the United States, and has been divided up by mutual agreement between Great Britain, France, Belgium and Portugal. It comprises some of the richest and most fertile land on the globe but it rests under a curse, the sleeping sickness.

This mysterious malady, that has laid waste a large part of the Dark Continent, is now known to be due to a minute parasite that lives in the blood of man and beast, and is called a trypanosome. When you look at one through a microscope you would not think that so little a creature could have so long a name or do so much harm. It looks like a smashed mosquito wiggler or a stickless kite. It propels itself along by sculling with its whip-like tail. The tsetse fly gets its living by sucking the blood of wild animals, cattle and human beings, and in so doing peddles about the microbe from sick to well. There are various sorts of trypanosomes and blood-sucking flies, each having its own habits and routes, but anyhow the infected individual suffers at first from fever and gradually sinks into an insensibility, from which the sleeper rarely wakes. This sort of sleeping sickness is peculiar to Africa and has nothing in common with the disease that has recently appeared in America except the name and somnolent symptom.

In the latter part of the last century when Europeans invaded the interior of Africa they found this micro-organism the most dangerous of the wild animals to be combated. Lions and elephants could be killed, but the tsetse fly was too small to be shot and the trypanosome was too small to be seen. How to destroy the parasite without harming the host was the question.

The first sign of a solution of the problem came in 1904 when the German physician Ehrlich and his Japanese assistant, Shiga, discovered an aniline dye which injected into the blood of a person seized with sleeping sickness would kill the parasite. This dye was named "trypan red." Two years later Mesnil and Nicolle of the Pasteur Institute of Paris found that several similar dyes made by the Bayer Dye Works were also serviceable. These dye-drugs were all derivatives of naphthalene, familiar to us all since little white balls of



DR. FREDERICK BELDING POWER

U. S. Bureau of Chemistry, who has been awarded the Flueckinger gold medal by the Society of Swiss Chemists for "invaluable work on alkaloids and etheral oil."

it drop from our clothes when we shake them out in the fall.

But none of the known dyes were sufficiently active so that they were certain to clean out the pests from the body of the patient. The Bayer company has quietly continued its search for something more powerful and equally innocuous and has at last, after 204 compounds had been made and found unsatisfactory, got one that cures. It is not a dye but a white powder, soluble in water. It was tried successfully on mice, rats, guinea-pigs, rabbits, dogs and horses and finally upon man. An English patient who had suffered from sleeping sickness for a year and on whom all the customary remedies had been tried in vain, was cured by four doses amounting altogether to an eighth of an ounce. Better still it is found that a single dose will make a person immune to the disease for a long period even if infected by the fly. It is also said that the new medicine or some of its relatives will cure malaria and other tropical fevers.

Whether Bayer 205 is a plain naphthalene derivative like the earlier efforts of the firm or whether it contains arsenic like "606", which is used to destroy a similar blood parasite, is not known to the outside world for the composition is kept secret. Small samples of the drug have been furnished for experimentation to Belgian, British and American physicians but under pledge of professional secrecy. At a recent meeting in Hamburg of the German Association of Tropical Medicine one of the speakers said:

"Bayer 205 is the key to tropical Africa, and consequently the key to all the colonies. The German government must, therefore, be required to safeguard this discovery for Germany. Its value is such that any privilege of a share in it granted to other nations must be made conditional upon the restoration to Germany of her colonial empire."

It is indeed the irony of fate that the Germans should have found the means of making their colonies colonizable only after they had lost them and that their discovery must go to benefit those who took their African territories from them. But this suggestion of buying back a million square miles for a single chemical symbol can hardly be taken seriously. The chemists of other countries are already hot on their trail and with what clues they have will doubtless eventually find out the composition of the mysterious medicine. But whether Germany makes anything out of it or not, it may turn out that her scientists by this discovery will bring as much benefit to Africa as her soldiers did damage in Europe.

THE WASTEFULNESS OF AGRICULTURE

To those superstitious people who hold that nature is perfect in all her works it must come as a shock to learn that one of the most wonderful of all natural processes and the one on which all life depends, that is, the storing up of solar energy in the green leaf, is far more inefficient than any of man's machines. It is a poor steam engine that can not turn into mechanical work at least twelve per cent. of the heat energy that is fed into it in the form of coal. But a green leaf is not able to catch and hold more than one per cent. of the radiant energy that falls upon it from the sun.

What solar energy is caught and held is stored up, so to speak, in the form of starchy and woody stuffs from which the energy can be released in the form of heat when the stuff is burned. But if it is food we want from the plant instead of fuel its yield is still more limited, for we human beings with our restricted digestive apparatus can not get nutriment out of the woody fiber as we can out of the sugar and starch.

MEMBERS OF THE NATIONAL ACADEMY OF SCIENCES
At the Entrance of Schermerhorn Hall, Columbia University.

How much then of the solar energy that falls, say, on a wheat field can we get out in the form of the edible grain to furnish us with muscular energy?

Dr. H. A. Spoehr, of the Carmel Coastal Laboratory of the Carnegie Institution of Washington, has been figuring on this and reaches some startling results. An acre of ground receives in six hours of sunshine as much heat energy as would be produced by the combustion of 16.4 tons of coal. In a growing season of ninety days at this rate per day the total income of energy would amount to 1,476 tons of coal.

Now what is the yield, likewise calculated in terms of heat units derivable from coal? Taking the very large crop of 50 bushels of wheat per acre and calling it all starch, we get an energy equivalent of only less than two thirds of one ton of coal.

That is to say, the farmer has received as free bounty from heaven 2,300 times as much energy as he has been able to market in the shape of food.

But don't call the farmer an inefficient fellow. He only began the cultivation of wheat in the New Stone Age, say seven thousand years ago, and see how much he has improved upon nature in the matter of yield.

And don't blame Dame Nature. She is quite indifferent to our blame or praise, but is very ready to cooperate with us when we take the trouble to learn her ways and show how they can be improved. This chlorophyll process for the fixation of solar energy, this green leaf laboratory, was one of nature's first inventions, made perhaps sixty million years ago, and she was so well satisfied with it that she made it the foundation stone of all earthly life and has kept it substantially unchanged to this day.

And man is not yet able to imitate nature in this particular process, let alone surpass her. Chemists have found it possible to make some of the simpler sugars, but only in very small amounts after long and expensive labor in the laboratory. Nothing like the neat and noiseless way that any leaf can carry it out. An effort is being made to get chemists and biologists to cooperate in working out the solution of the secret of photosynthesis—which is Greek for the constructive process of light. A "photosynthesis symposium" is scheduled for the Boston meeting of the American Association for the Advancement of Science, the last week in December, and it is hoped that this may stimulate research in this vital problem.

WHAT IS THE MATTER WITH THE ARTISTS

THE most common remark to be overheard at an exhibition of ultra-modern art is, "Why, these artists must be crazy!" Now to call another man "crazy" is not enlightening. It is too easy and explains nothing. Besides each one of us thinks those who differ from us in opinion, and especially in taste, are a bit wrong in the head.

But if, instead of recklessly applying the word "crazy" to everything we do not like or understand, we should analyze ourselves to find what is the reason, or rather the cause, of our instinctive repugnance, it might be helpful to us. It may be that we hate the new thing merely beause it is new. If so, we may say that we are merely suffering from neophobia. Giving a complaint a Greek name is a great consolation as every physician knows.

Or we may set a psychological expert to analyzing the people who are disturbing our minds by their unconventional notions and so find out why they show such strange tastes. Dr. Stewart Paton, lecturer on psychiatry at Princeton University, has made such an analysis of modern art in his new book, "Signs of Sanity," and

GREGOR MENDEL AND HIS FELLOW TEACHERS

in the secondary school of Brünn. Mendel in clerical attire is seated on the right. The centenary of the birth of Mendel and his remarkable contributions to heredity and genetics were celebrated this summer under the auspices of the University of Brünn. The photograph is printed by the courtesy of Professor M. M. Metcalf, to whom it was given by the monastery at Brünn.

has come to the following conclusion:

"The futurist art expresses, not intellectual superiority, but very primitive emotion, and illustrates a reversion to ideas and ideals of the Stone Age. It is not what its devotees claim for it, the product of conscious intellectualization of the creative spirit. The futurist, like a good many other people who are trying to find some compensation for defects in their personality, instead of being an interpreter of new sensations and emotions, is expressing those that were more characteristic of man during the early periods of his history than they are of human beings to-day. The literary, as well as musical moderns, in their unsuccessful efforts to find new and startling lines of expression, have practically only succeeded in recalling some forgotten memories of very primitive ancestors. The futurists practically depend for their inspiration upon the revival of subconscious mental activities that extend far back in the history of the race, and they surrendor unconsciously to the primitive vision and emotions of an almost forgotten past. Their philosophy of art is based almost entirely upon illusion and fallacy; for instead of listening to reason, they have simply succeeded in giving expression to very primitive tendencies that have been successfully inhibited by the real intellectuals who have contributed to the progress of civilization. It is of great assistance in preserving our sanity to have some appreciation of the nature and genesis of these primitive impulses and not to make the mistake of believing them to be evidences of intellectuality."

This explains why successive waves of fads in art, each more extravagant than the last, have swept over the world and shows their connection with other signs of the times. The recrudescence of superstition, the revival of race hatreds, the growth of belligerency, the glorification of brutality, the defiance of law, the contempt for intellectuality, the prevailing tendencies in music, dancing, literature and dress, as well as in painting and sculpture, all indicate a reversion to that primitive psychology that arose out of the war, or out of which war arose. The Pre-Raphaelite movement of the last century has become the Pre-Troglodyte movement of the present century. Young artists who used to go to Paris or Rome for study now seek inspiration in Tahiti or the Congo.

But while recognizing the fact that futuristic art points backward we may continue to admire it or be amused by it, according to our taste. A dip into the primitive or a flight into the unconventional may not be a bad thing for us once in a while. It will keep us from getting stuck in the mud. But if it should become epidemic and chronic—then, goodbye, civilization.

SCIENTIFIC ITEMS

WE record with regret the death of Elias Judah Durand, chairman of the department of botany in the University of Minnesota; of Albert Henry Buck, from 1887 to 1904, professor of otology in Columbia University; Charles Franklin Emerson, dean emeritus of Dartmouth College, and formerly professor of astronomy and physics; Charles Albert Fischer, professor of mathematics and astronomy at Trinity College; of Emil Holmgren, professor of histology at Stockholm; of Lassar-Cohn, professor of chemistry at Königsberg; and of Oscar Hertwig, director of the Institute of Histology at the University of Berlin.

BIOGRAPHIES of members of the National Academy of Sciences who died during the year 1922 will be prepared as follows: A. Graham Bell, by Dr. John J. Carty; J. C. Branner, by Professor Bailey Willis; Wm. S. Halsted, by Dr. Wm. H. Welch; Henry M. Howe, by Dr. Edwin H. Hall; Alfred G. Mayor, by Dr. Charles B. Davenport; Alexander Smith, by Professor W. A. Noyes.

To Dr. Fridtjof Nansen, the Norwegian Arctic explorer and zoologist, has been awarded the Nobel Peace Prize for his work in relieving the starving populations of Russia and Asia Minor and for his endeavors to promote the brotherhood of nations.

THE Lalande Medal of the Paris Academy of Sciences has been awarded to Dr. Henry Norris Russell, director of the Princeton Observatory. The Janssen Medal goes to Dr. Carl Stormer, professor of pure mathematics at the University of Christiana, for his work on the aurora borealis.

AT the anniversary meeting of the Royal Society on November 30, its awards are to be conferred as follows: Royal medal to Professor C. T. R. Wilson, for his researches on condensation nuclei and atmospheric electricity, and to Professor J. Barcroft, for his researches in physiology, especially in respiration; the Copley medal to Sir Ernest Rutherford, for his researches in radioactivity and atomic structure; the Rumford medal to Professor Pieter Zeeman, for his researches in optics; the Davy medal to Professor J. F. Thorpe, for his researches in synthetic organic chemistry; the Darwin medal to Professor R. C. Punnett, for his researches in the science of genetics; the Buchanan medal to Sir David Bruce, for his researches and discoveries in tropical medicine; the Sylvester medal to Professor T. Levi-Civita, for his researches in geometry and mechanics; and the Hughes medal to Dr. F. W. Aston, for his discovery of isotopes by the method of positive rays.